Large area GEM tracking

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University of Virginia, Charlottesville, VA

fsPHENIX Workshop, Iowa State Univ. March 12, 2016

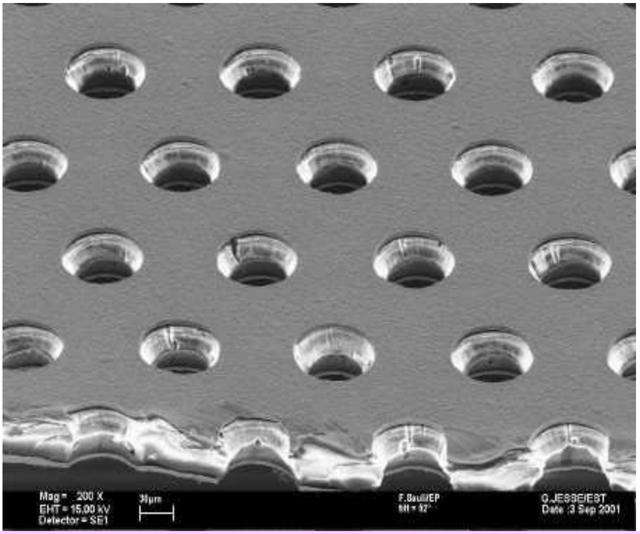
Outline

- ✓ Basics of GEM detectors
- ✓ Large area GEM
- ✓ Large GEM R&D in US
- ✓ RD51 Collaboration

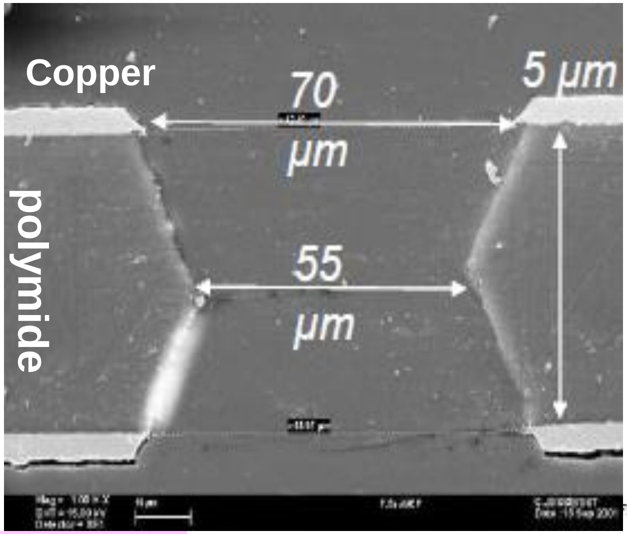
Basics of GEM detector: GEM Foil as Electron Amplification

- Thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm^2
- Voltage of ~ 350 V across the Cu electrode creates a strong field in the hole leading to amplification
- The ionization pattern is preserved by design with the electric field focusing the charges inside the holes

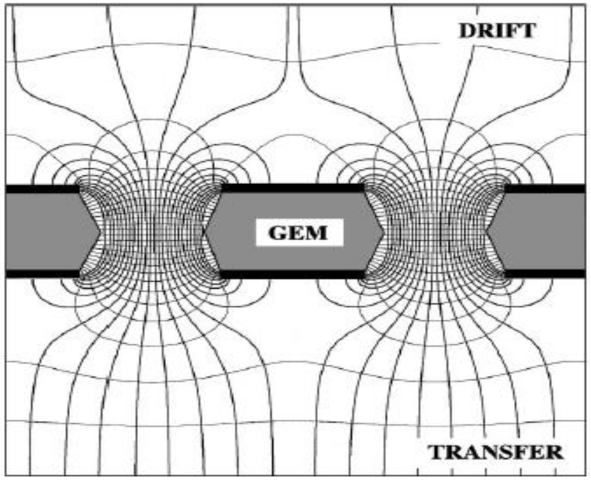
GEM foil



GEM hole parameters



E Field pattern



igure 34 Electric field and equipotentials lines in the gas electron multiplier.

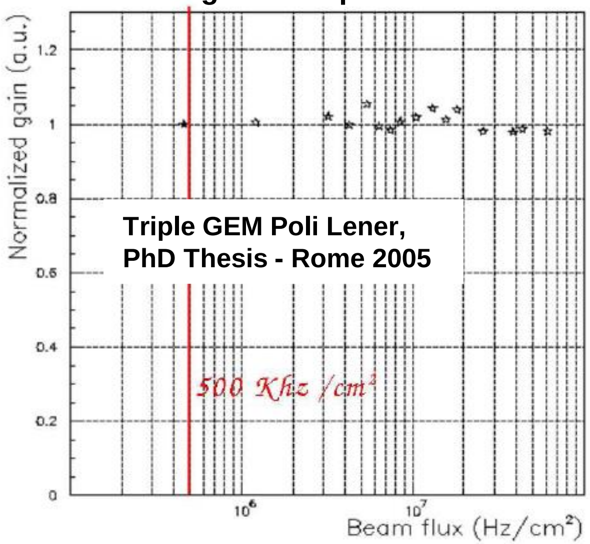
F. Sauli, Nucl. Instr. and Meth. A386(1997)531

UNIQUE FEATURE

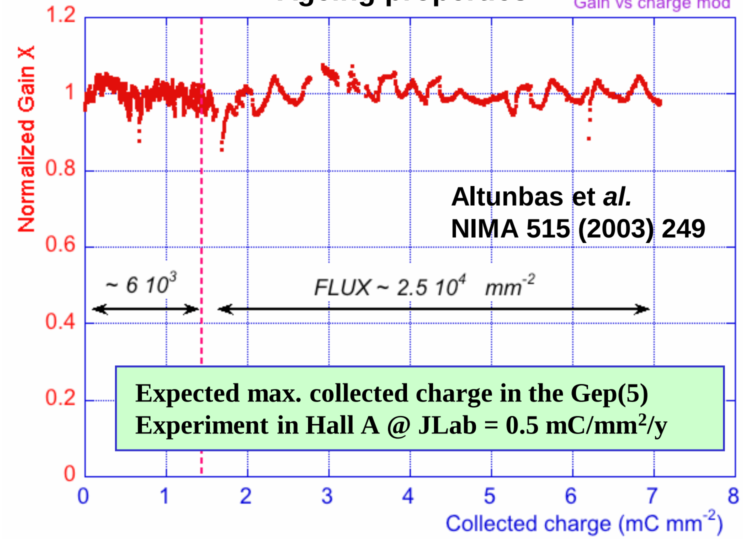
Charge amplification is decoupled from the charge collection ⇨ Multi stage amplification

Basics of GEM Detectors: Performances

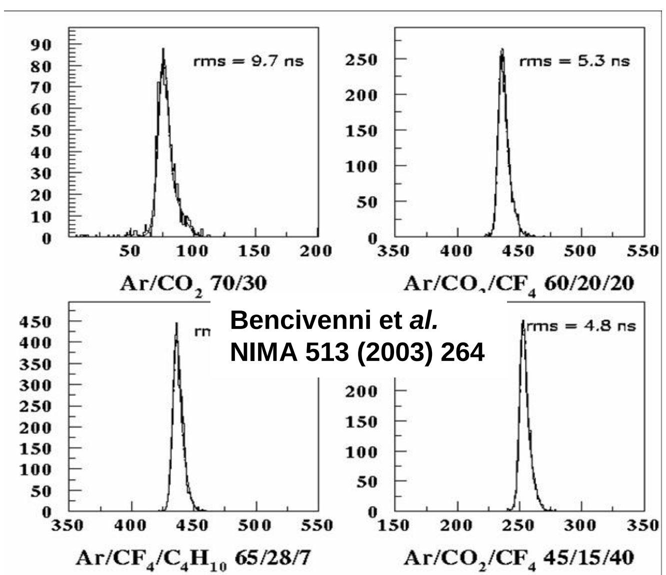
High rate capabilities



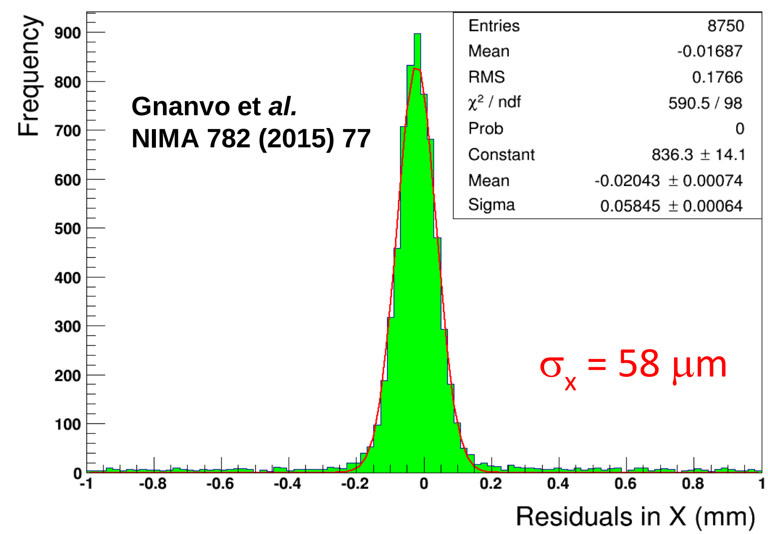
Ageing properties



Timing resolution



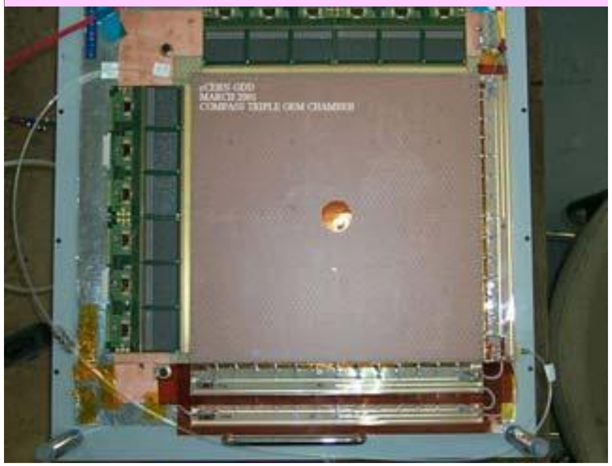
Position resolution

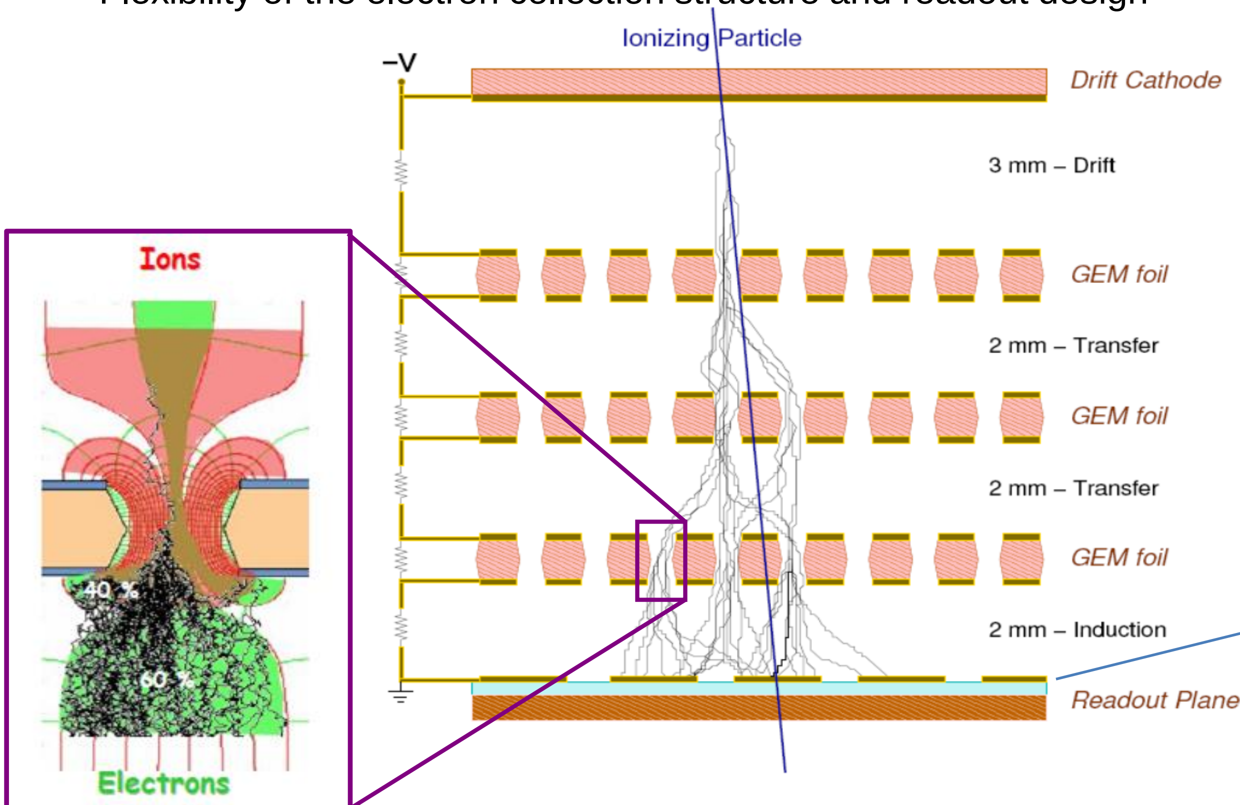


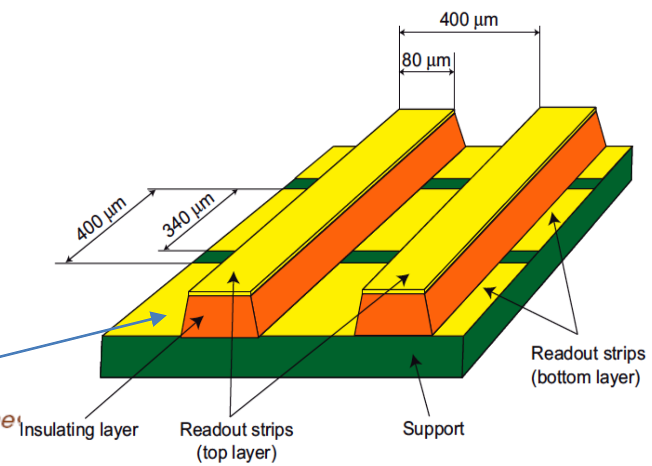
Basics of GEM Detectors: The COMPASS Triple-GEM Design

- 3 GEM foils with cascade amplification
- ~ 350 V across the foil ensure an average gain per foil of 20 to 25
  - ✓ Low discharge probability
  - ✓ Electric field ⇨ focus electrons to the holes better spatial resolution
  - ✓ Structure minimize electron flow back
  - ✓ Flexibility of the electron collection structure and readout design

COMPASS @ CERN first use of GEM in HEP Experiment







2D strips (pitch 400 μm) readout on a Flexible 50 μm Kapton support

Large Area GEM

Large Area GEM: Single Mask Technique

Previously: Double mask
Limitation from mask alignment
⇨ max active area ~ 40×40 cm^2

Now: Single mask
No alignment required
⇨ Very large GEM foil

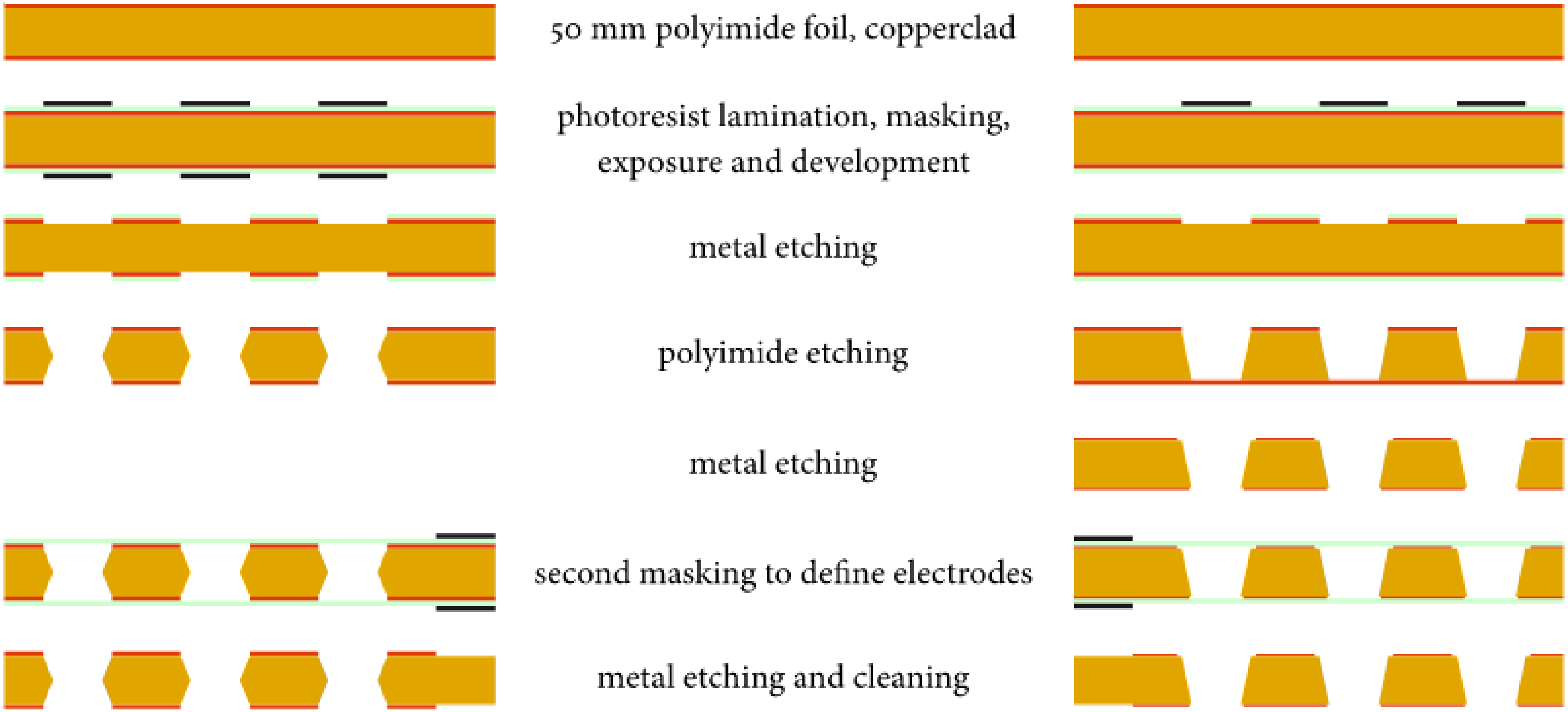
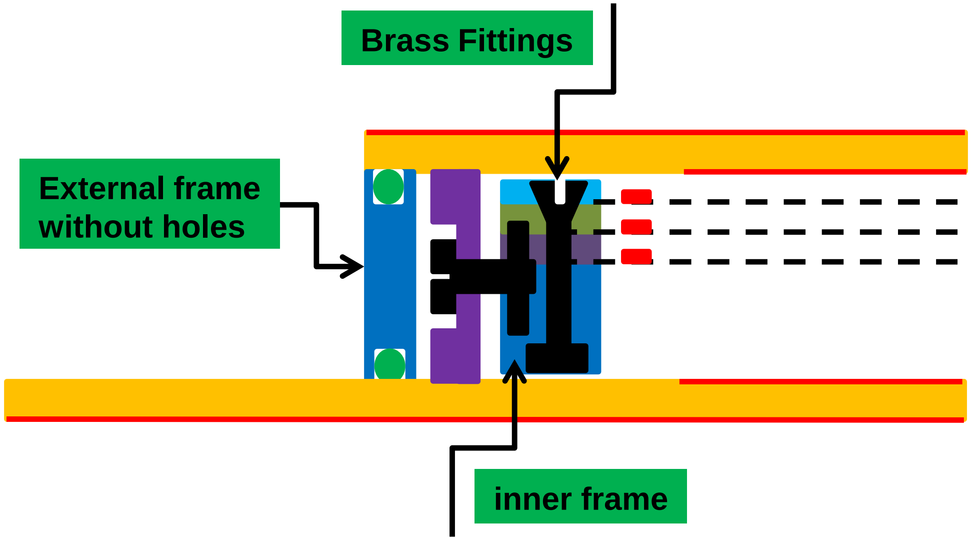


Figure 1. Schematic comparison of procedures for fabrication of a double-mask GEM (left) and a single-mask GEM (right).

Progress on large area GEMs Serge Duarte Pinto et al., JINST, November 26, 2009, [http://arxiv.org/pdf/0909.5039v2.pdf]

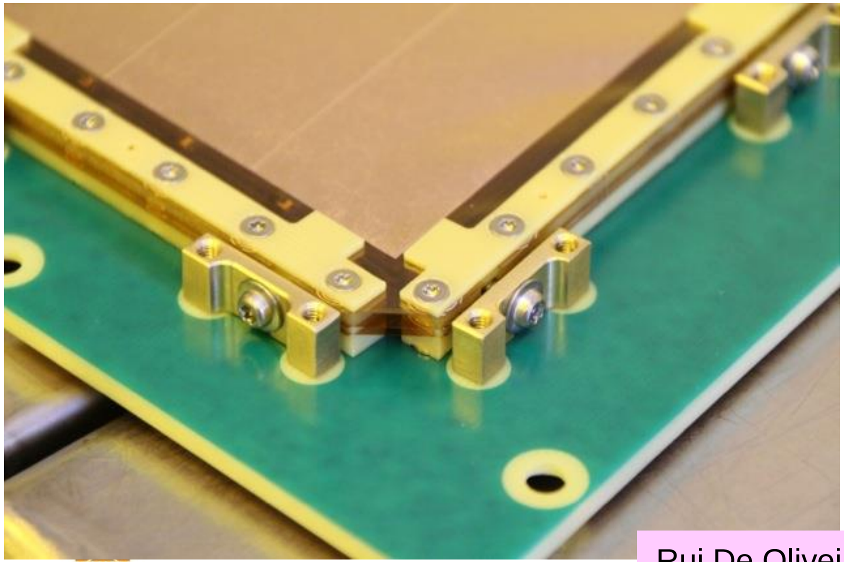
Large Area GEM: NS2 Assembly Technique

pioneered by CMS GEM Muon Upgrade collaboration & RD51

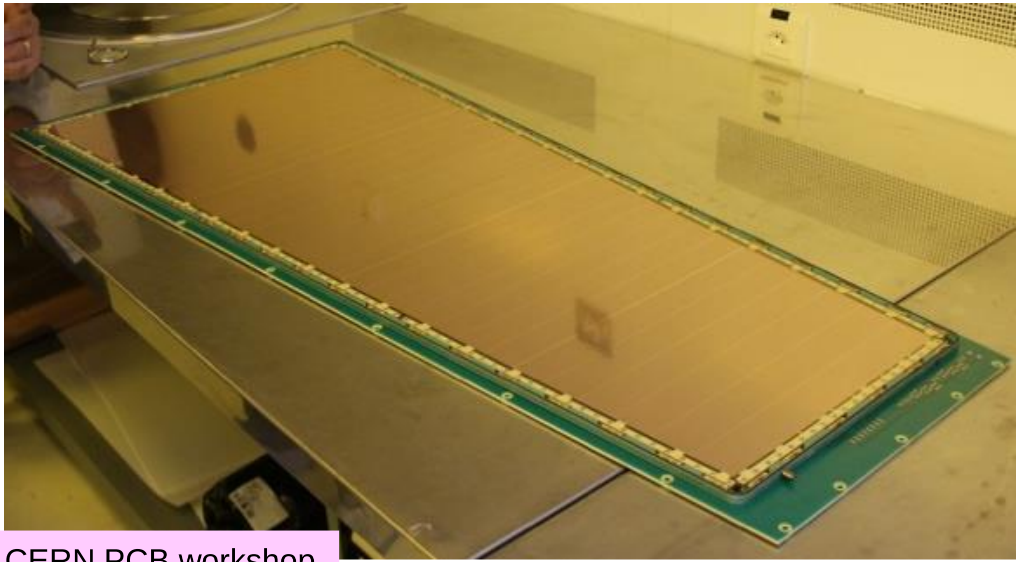


- Mechanical stretching with small frames with the use of a set of screws, fittings for the stretching
- Control of the stretching and the flatness of the GEMs
- No glue involved in the assembly
  Chamber can be re-opened
- No need for spacers in active area
- BUT: Lots of screws and rigid supports material
  critical for tracking detectors

Close view of 3 GEM stack with NS2 technique



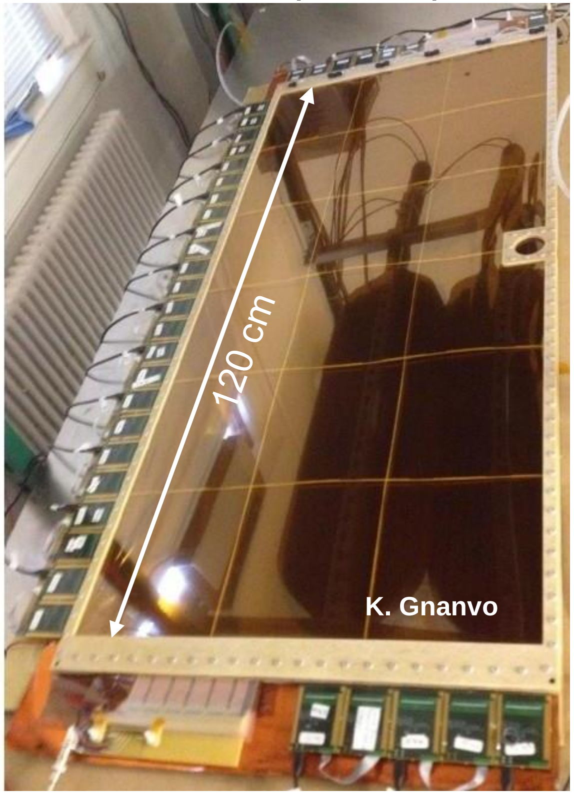
CMS GE1/1 NS2 detector assembly



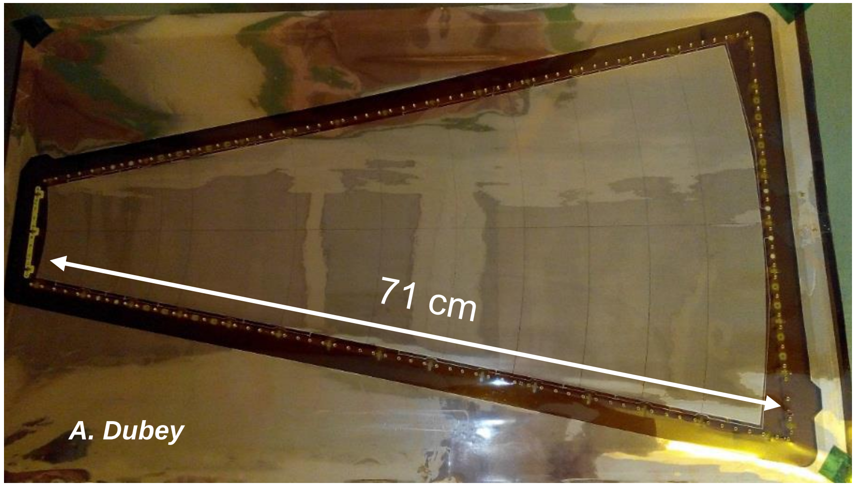
Rui De Oliveira, CERN PCB workshop

Large Area GEM for Tracking

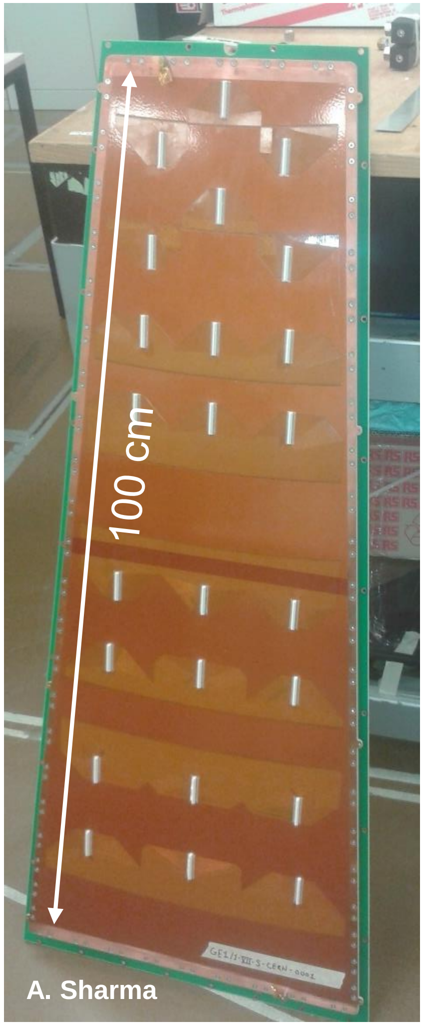
PRad GEMs (JLab, USA)



CBM MUCH (FAIR, Germany)



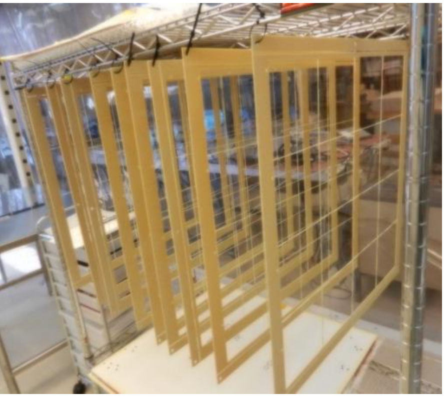
CMS GEM (CMS, CERN)



Large GEM R&D in the US

Large GEM in US: University of Virginia GEM R&D

Storage of the frames

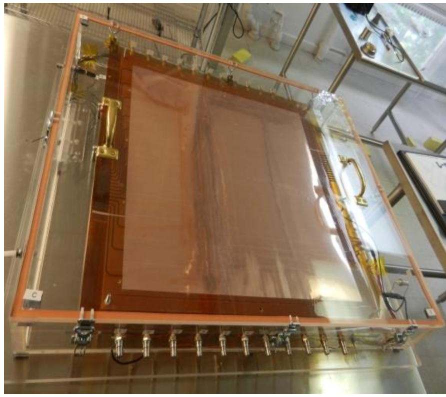


Frames holder for cleaning

Ultra sonic bath (USB)

(3 × 7 m^2) Class 1000 Clean Room

Storage of the framed foils

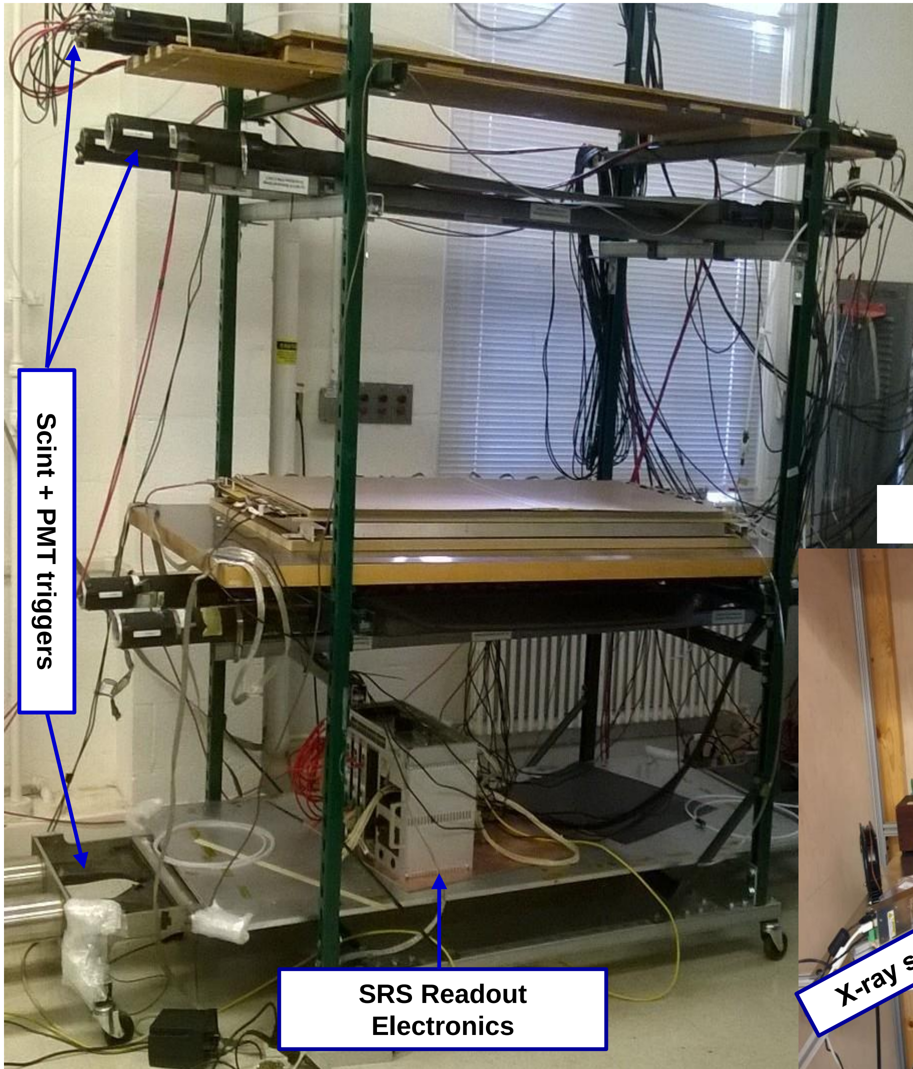


Glue dispenser

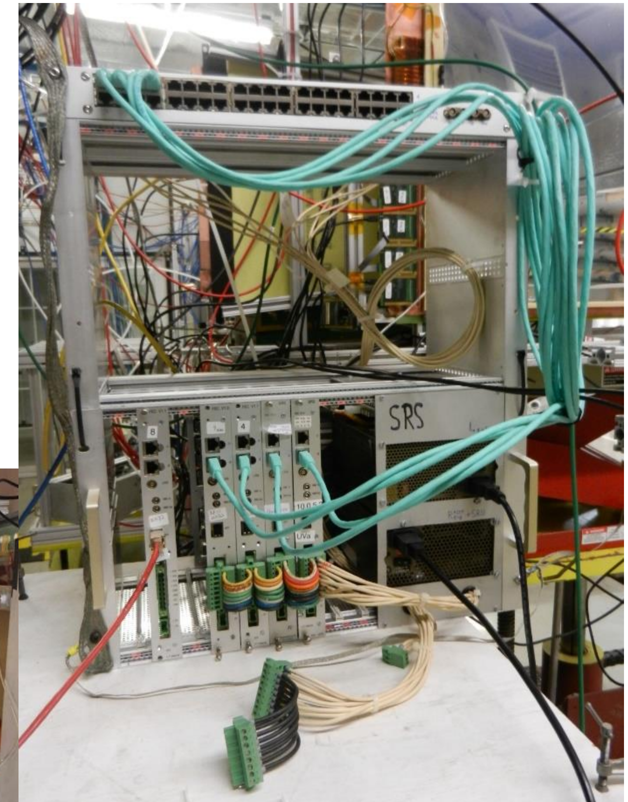
Tacky roller ➔ dust removal

Large GEM in US: University of Virginia GEM R&D

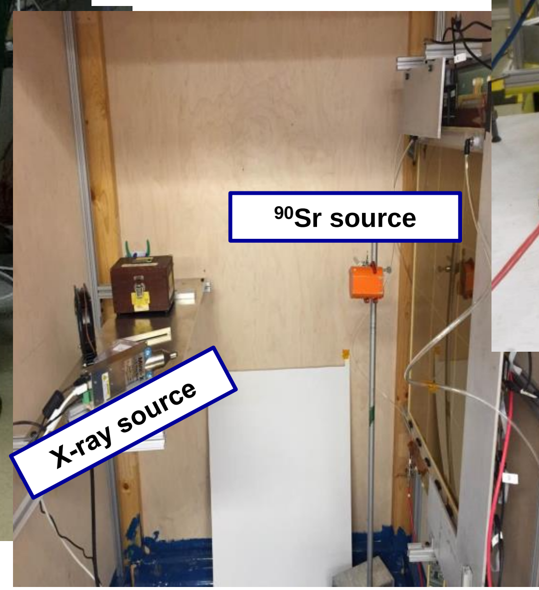
Large cosmic test bench



Readout Electronics: 12K channels



X-ray high rate test box



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Large GEM in US: University of Virginia GEM R&D

- **29 modules (60 x 50 cm^2) built @ UVa**
- **All the 29 modules passed the final test**
- **16 more in the next 12 months**

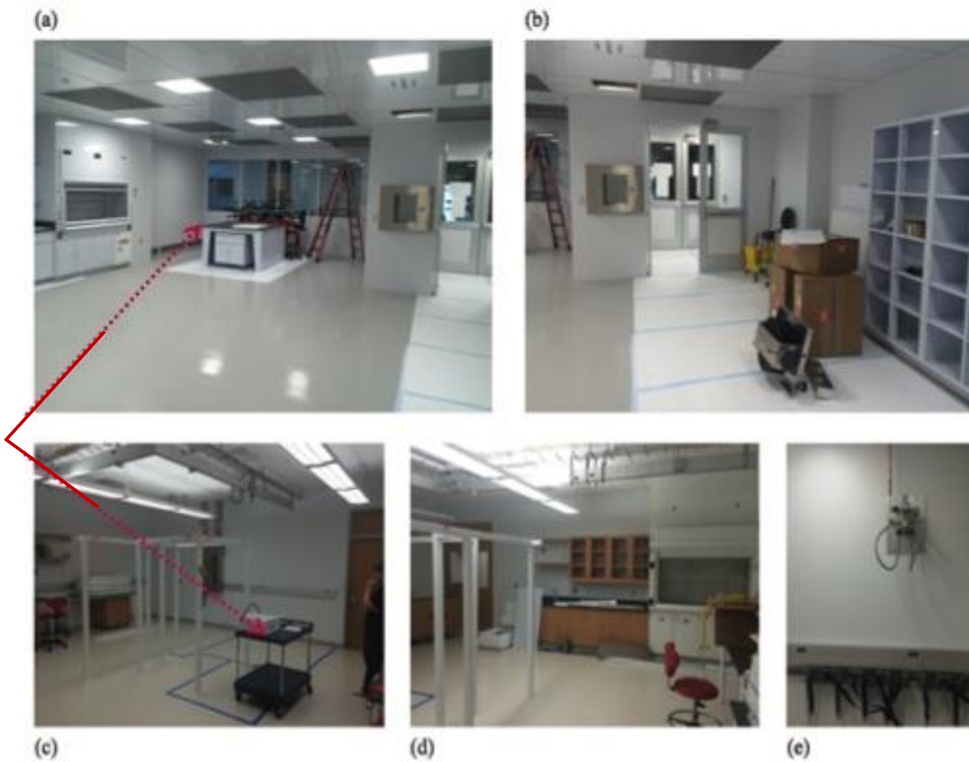
SBS GEMs currently stored at UVa

Large GEM in US: Temple University GEM R&D

- Major effort on STAR Forward GEM Tracker completed with full installation in fall 2012 - 24 large triple-GEM detectors arranged on disks / 30720 channels (APV25-S1)
- Large group at TU with fully equipped micro-pattern detector laboratory (Detector lab and permanent clear room facility) at new Science Education and Research Center with outstanding resources
- Major funded EIC R&D effort on large triple-GEM detectors focusing on light-weight structures and commercial fabrication of various detector components

New Laboratory facilities at Temple University

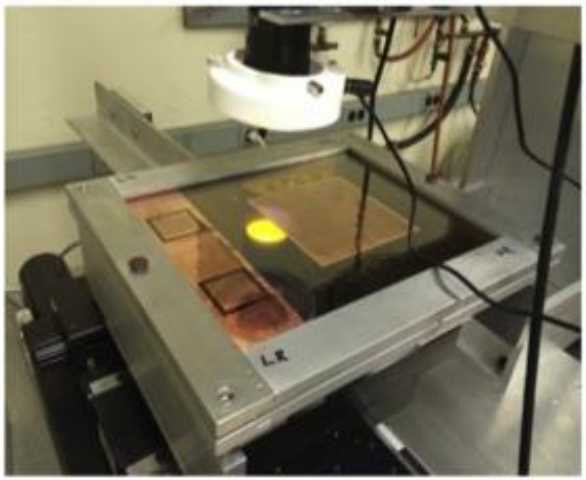
Note: GEM Clean Room (a/b) is ready (Move-in soon) / GEM detector (c/d/e) lab move-in completed. Both labs will be equipped with new Newport Optical tables (6'x4') provided by Temple University, CST (Cost: $25k)



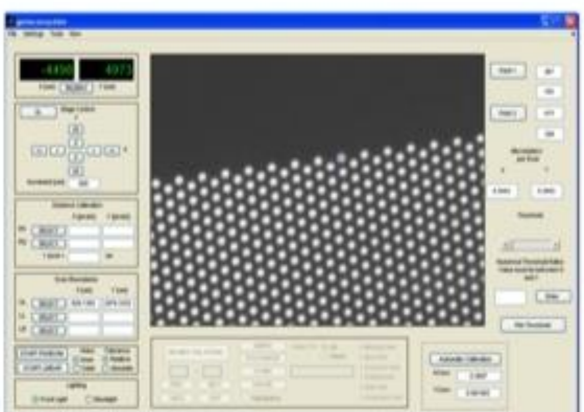
Large GEM in US: Temple University GEM R&D

Single mask GEM Foil: CCD scan setup

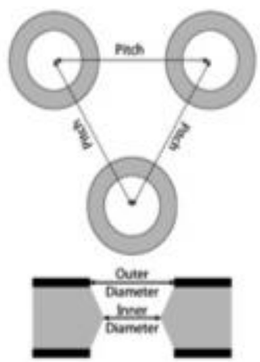
- ✓ 2D scanning table with CCD camera fully automated
- ✓ Scan GEM foils to measure hole diameter and pitch
- ✓ Unique world-wide setup in micro-pattern detector
- ✓ Critical for feedback in development and QA stage!



(a)

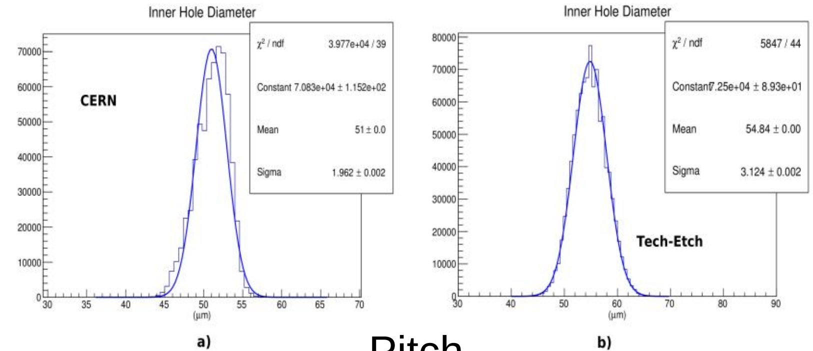


(b)

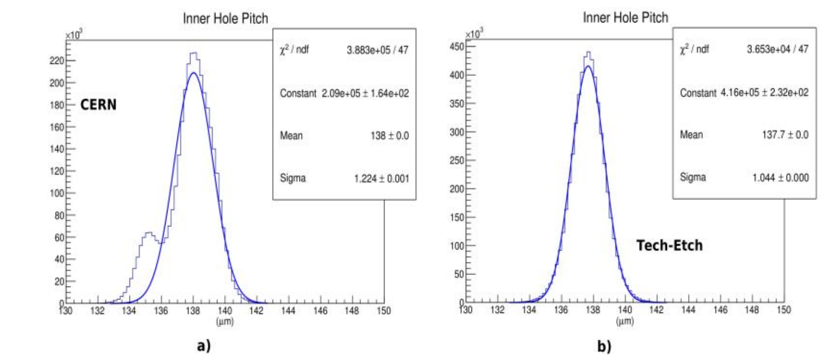


(c)

Inner Hole Diameter



Pitch



- Inner hole diameter and pitch are compared between a Tech-Etch and CERN (Only 1 CERN foil has been optically scanned) single-mask 10 X 10 cm^2 foil.
- Mean inner hole diameters between the two foils are similar size.
- The mean pitch between the two foils is also have similar values.
- However a double peak structure is present in the CERN pitch distribution.

GEM in Experiments: @ JLab

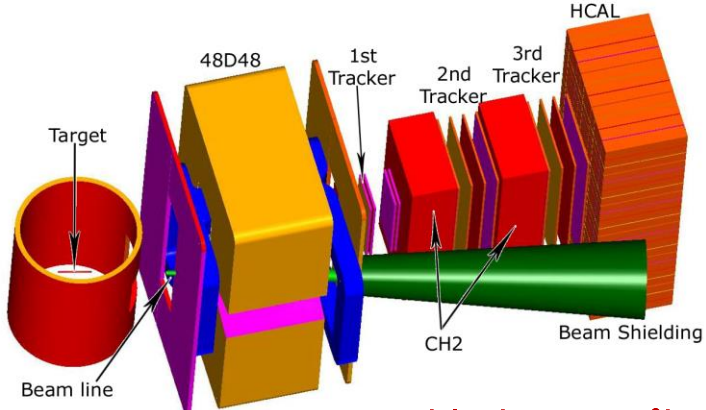
GEM Trackers, Super BigBite Spectrometer (SBS), hall A

SBS physics program

- GEP : 12 $(GeV/c)^2$
- GMN: 13.5 $(GeV/c)^2$
- GEN: 10 $(GeV/c)^2$
- SSA in nSIDIS: 30,000 gain vs HERMES

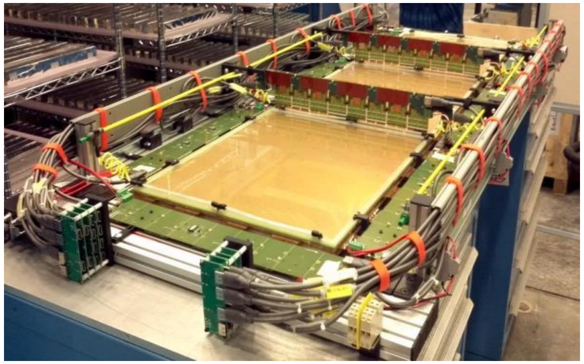
================================

- A1n/d2n – gain ~ 20-30 compared with HMS/SHMS
- TDIS meson DIS
- WACS-ALL, full proposal, 100x gain in productivity
- GEnRP, ready for full proposal,10+x gain in productivity
- pol H(γ,φ p), H(γ,π^o p)
- PVDIS – gain 10-15 compared with two HRSs
- A1p/d2p – gain ~20-30
- D(e,e'd) - A,T20
- J/Psi as gluon probe of QCD – well matched to BB/SBS
- A(e,e'p), A(e,e'$\pi^{+/-}$)

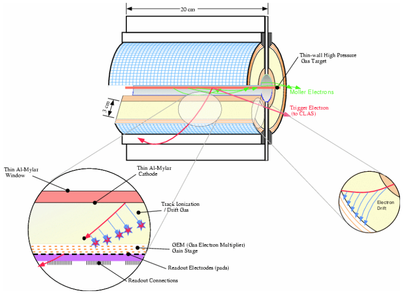


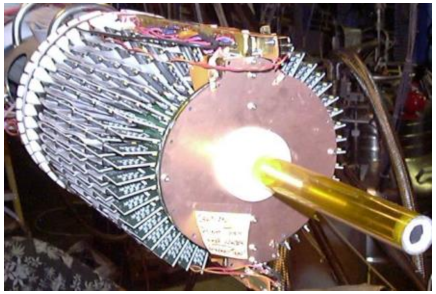
~60 GEM modules (60 $\times$ 50 cm^2)

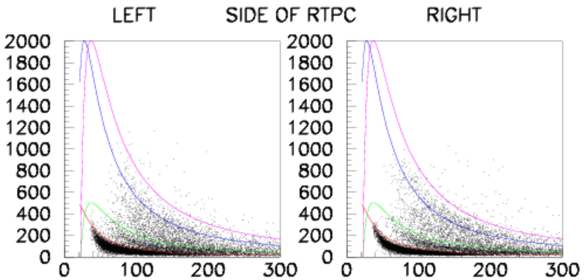
SBS 1st Tracker layer



GEM radial TPC, BoNUS, hall B





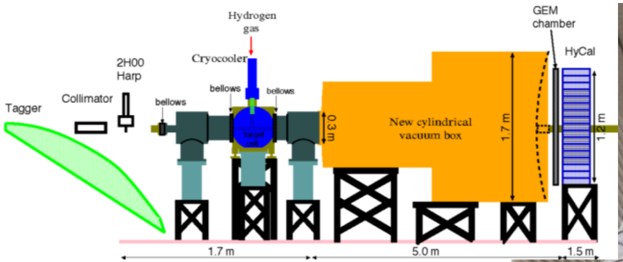


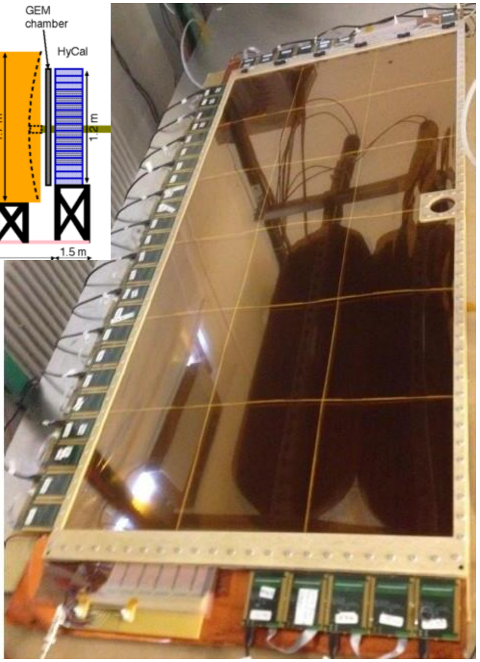
proton / deuteron / 3He / 4He

Ongoing projects with cylindrical GEMs: **BES III in China, BoNUs12 and TDIS @ Jlab**

H. Fenker, JLab

Prad GEMs, hall B



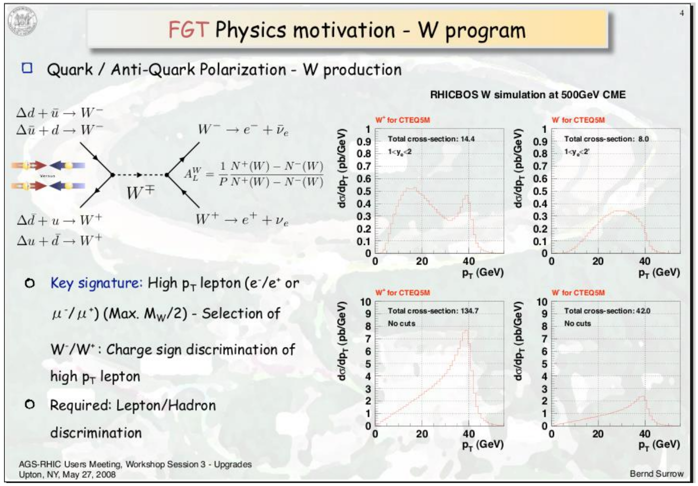


Specifications:

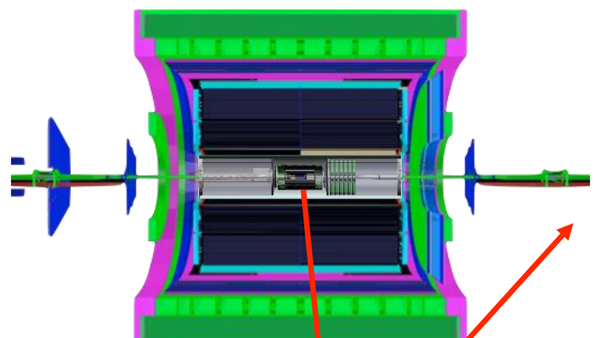
- 2 chambers: total active area: **(122x110 cm^2),** COMPASS readout
- factor of >10 improvements in coordinate resolutions
- similar improvements in Q2 resolution (very important)
- unbiased coordinate reconstruction
- increase Q2 range by including Pb-glass part

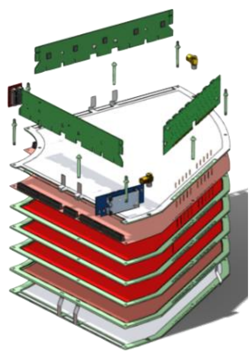
GEM in Experiments: @ BNL

Forward GEM Tracker (FGT), STAR



B. Surrow
AGS-RHIC Users Meeting, Workshop Upton, NY, 05/27, 2008



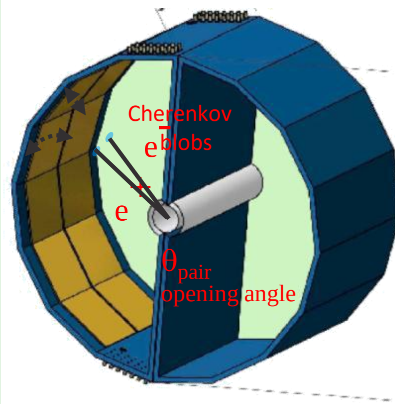


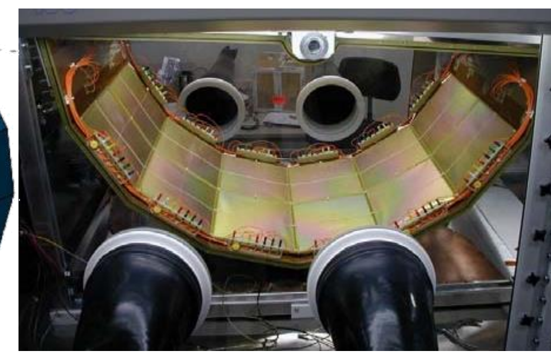
- STAR FGT GEM: 6 triple GEM disks around the beam
- Each disk: ID~7cm, OD ~40 cm
- 4 quarter section, ~ 0.14 m^2 each

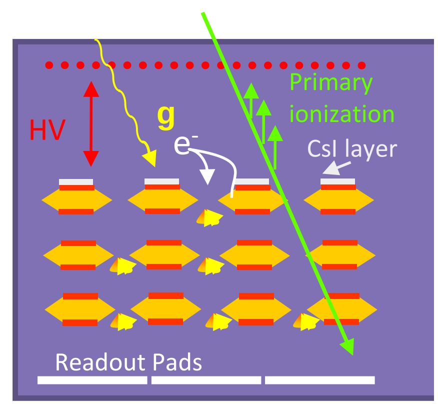
Hadron Blind Detector (HBD), PHENIX

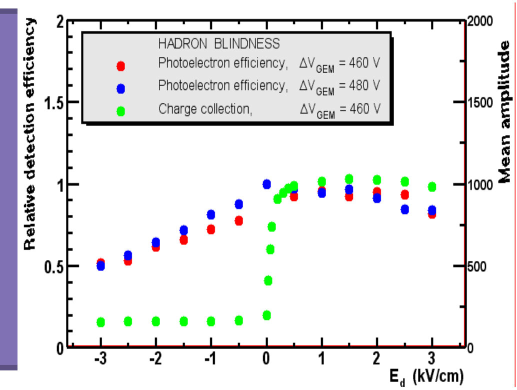
GOAL:
Detect double e- hits (signal) from e- from γ (background)
HDB close to the beam pipe
➪ Cerenkov blobs from two leptons = 2 pads
➪ Cerenkov blobs for single electron = 1 pad

BUT:
Detector should be insensitive to hadrons





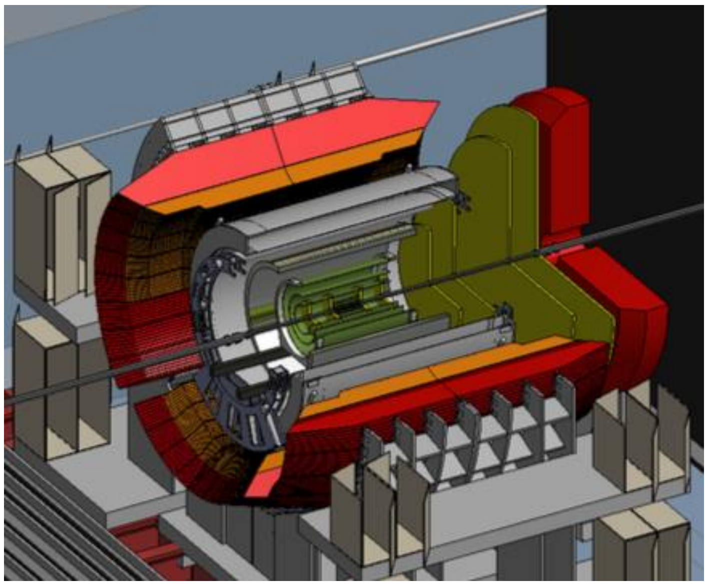




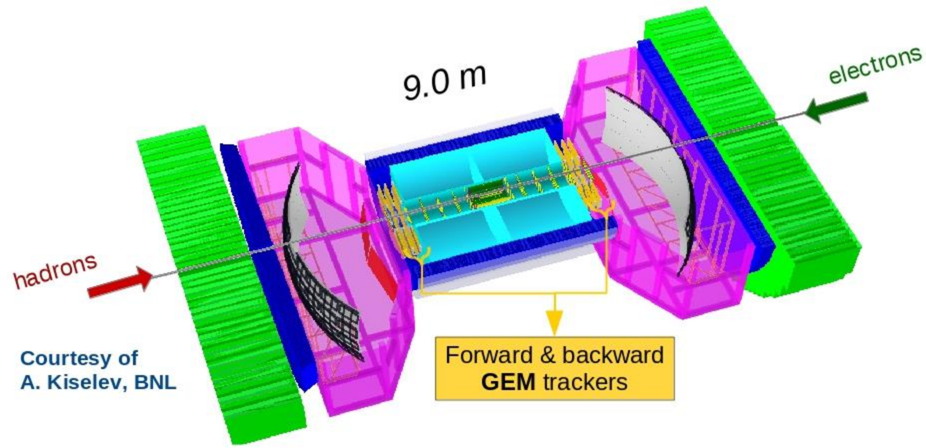
Large GEM R&D

Large GEM R&D: Forward Tracking for Future Projects

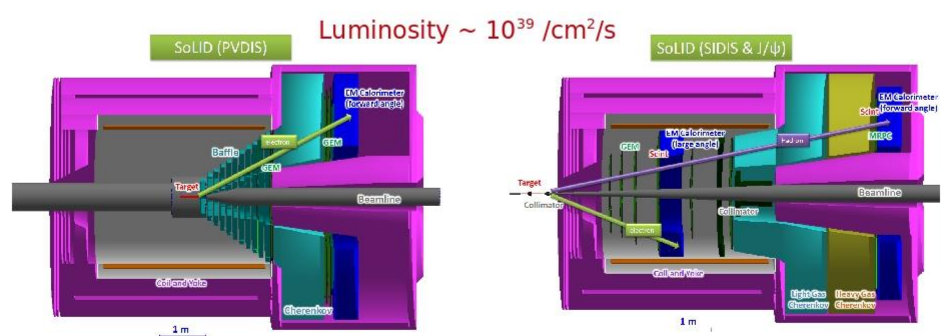
fsPHENIX Detector Conceptual design



EIC Detector Conceptual design



SoLID Conceptual design



Rate: 100 to 600 kHz/cm^2 (with baffles), GEANT4 estimation

Spatial Resolution: ~100 µm (sigma) in azimuthal direction

Total area: ~37 m^2 (30 sectors x 5 planes)

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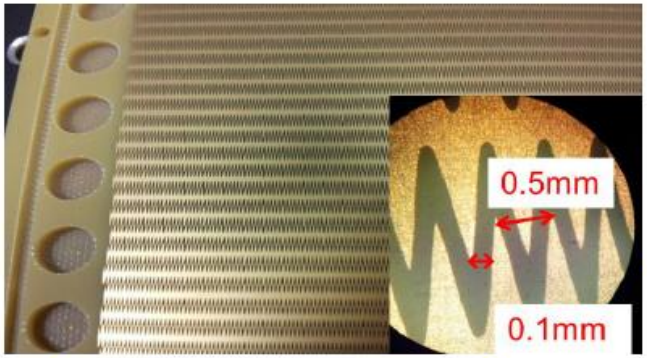
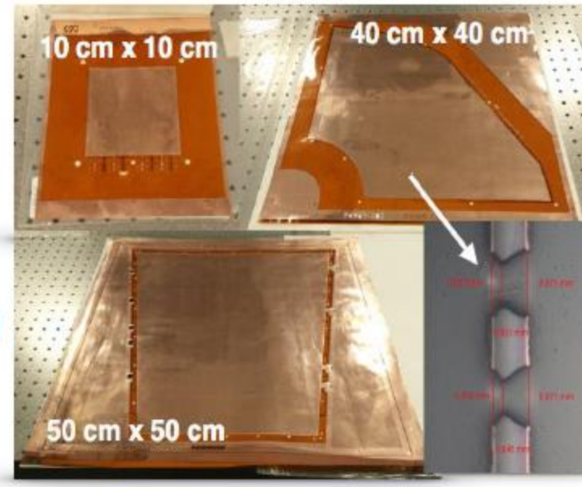
Large GEM R&D: Forward Trackers in the Future Projects



NIM A 811 (2016) 30-41

Florida Institute of Technology (FIT)

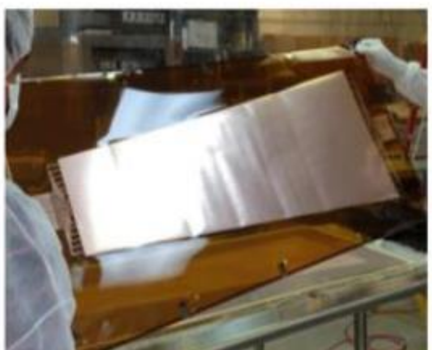
- Recently submitted a results of their large area (~1 m) triple-GEM detector to NIM A for publication.
- Successfully used zig-zag readout as a means to maintain good sp atial resolution while reducing number of readout channels needed
- σ_{φ} = 193 μrad

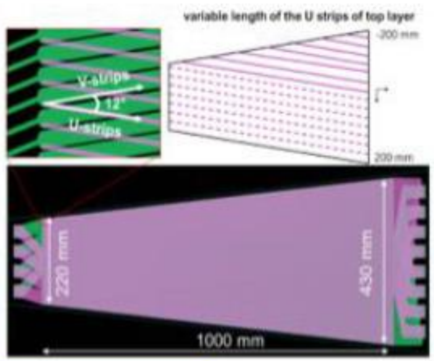


NIM A 802 (2015) 10-15

Temple University (TU)

- Have been working with US company Tech-Etch towards commercializing la rge-area GEM foils.
- Recently published results of electrical and geometrical foil quality





NIM A 808 (2016) 83-92

University of Virgina (UVa)

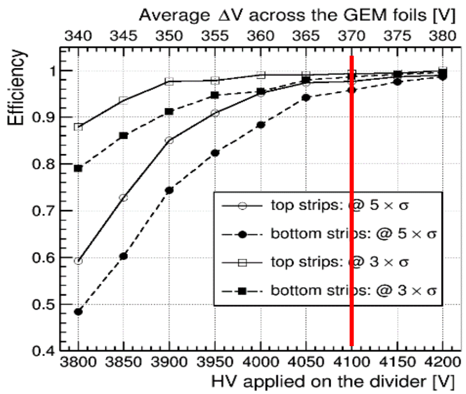
- Recently published results on their large-area (~1 - m)/ light weight triple GEM detector
- The detector successfully implemented 2D stereo -angle (U-V strips) readout
- σ_r = 550 μm, σ_{φ} = 60 μrad

Large GEM R&D: U-V Strips readout studies

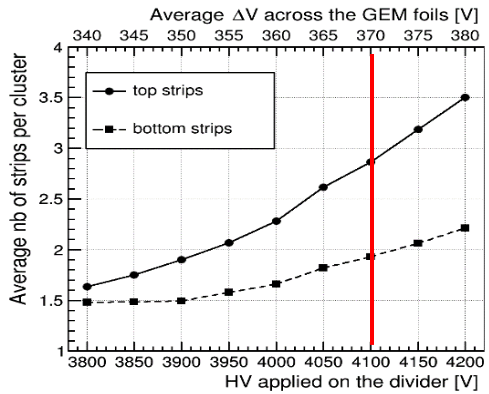
EIC-FT-GEM (SoLID) Prototype I

- Trapezoid shape **1-m long** triple-GEM (3-2-2-2): widths at the inner radius and outer radius equal **to 23 cm and 44 cm** respectively.
- Readout board: flexible 2D U-V strip readouts (COMPASS style) with a **pitch of 550 µm,** top layer (**140 µm, wide U-strips**) run parallel to one radial side of the detector and bottom layer (**490 µm, V-strips**) run parallel to the other side.
- Test beam results published in NIM A 808 (2016) 83-92

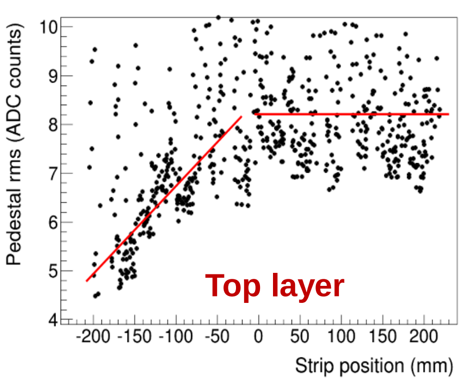
Efficiency vs. HV

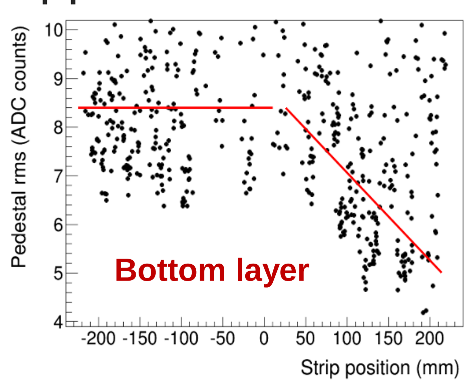


Cluster size vs. HV

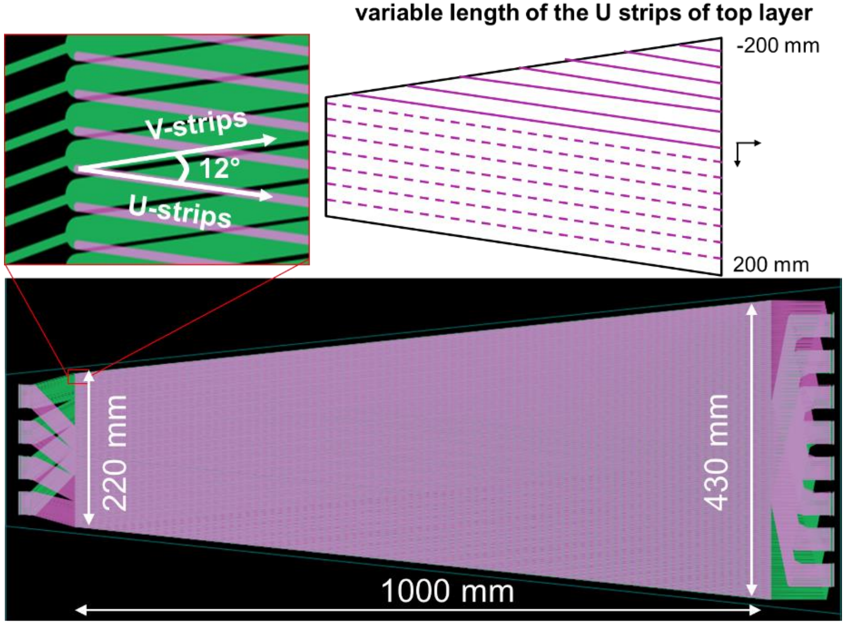


Distribution of the strip pedestal noise

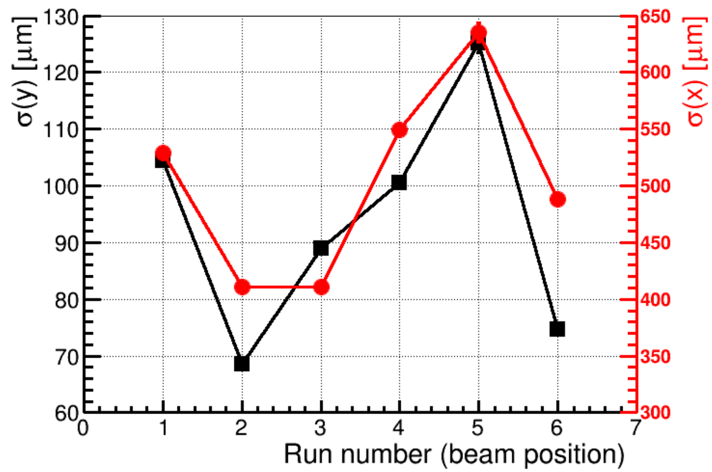




U-V strip Readout of EIC-SoLID GEM Proto I



Position resolution in x (radial) and y (azimuthal) on various locations on the chamber



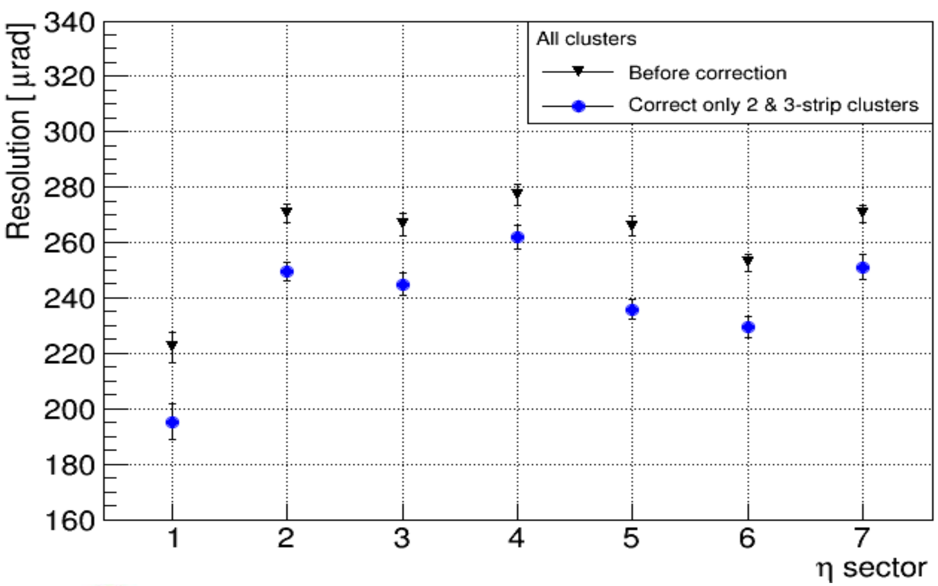
Large GEM R&D: Zigzag Strips readout studies

Aiwu Zhang

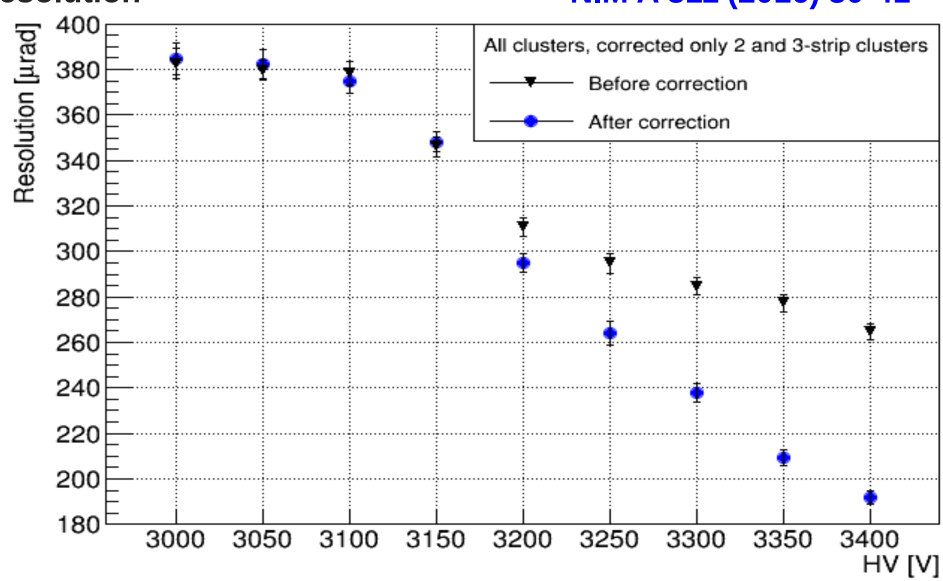
Motivation: due to large strip width and special structure of the zigzag r/o strips, cluster positions are not anymore accurate if we simply use the Center of Gravity (COG) method.
Method: we correct 2-strip and 3-strip clusters' positions separately using tracking information.
We define $\eta \overset{\text{def}}{=} s_g - s_{max}$ for each event. s_g is position from normal COG method, s_{max} is the strip number on which max. charge is collected. η-dependent response functions are obtained, and corrections are made based on these functions.

Position resolution

NIM A 811 (2016) 30-41



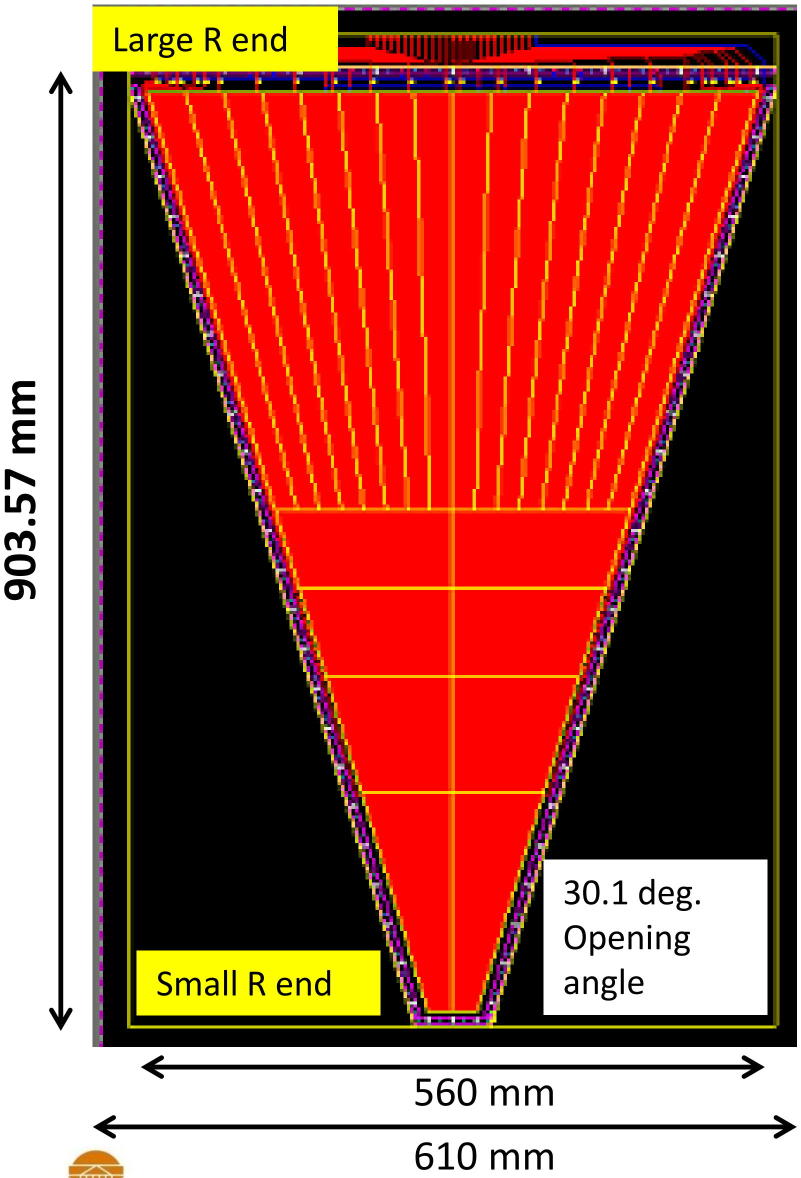
Position scan at 3200V



HV scan at at Position 1

Large GEM R&D: Common GEM foil design for EIC

(UVa, Florida Tech, Temple U.)



-> Foil width (at the large R end) is limited to **560 mm** due to material limit of 610 mm (25 mm margin is needed for foil production).

-> A trapezoid foil with a length of **903.57 mm**, widths at both ends of **43 mm** and **529 mm** (for the active area).

-> Opening angle of the trapezoid is **30.1 deg.**, allows some overlap when making a disk from 12 same type detectors.

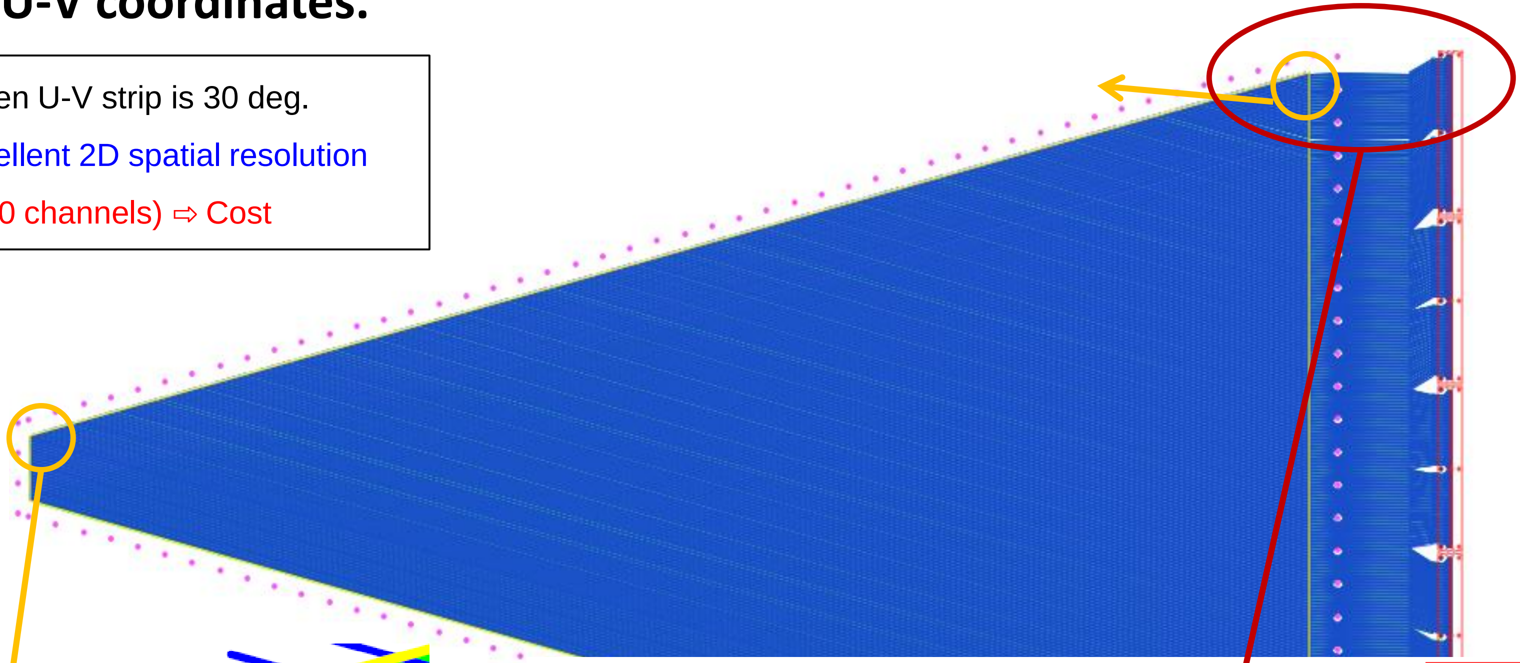
-> Active area is divided into 8 HV sectors in R direction at inner R and 18 HV sectors in azimuthal directions at outer R. This allows to reduce discharge energy if happens. Each sector **~100 cm^2** and gaps between sectors are 0.1 mm.

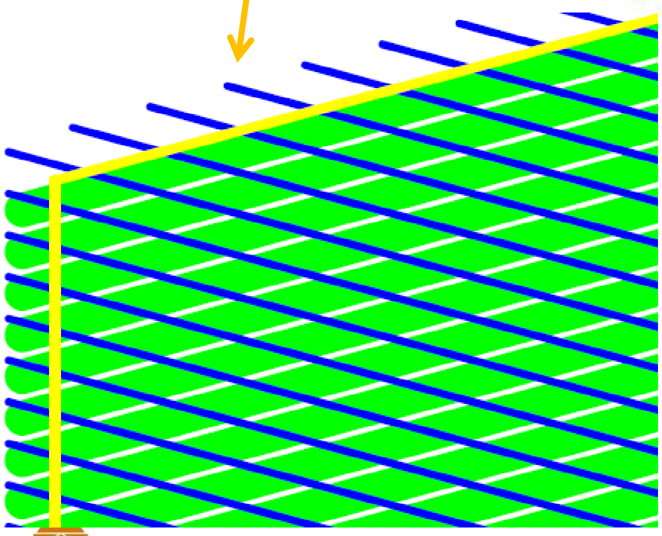
-> HV connections are to be made from the large R end.

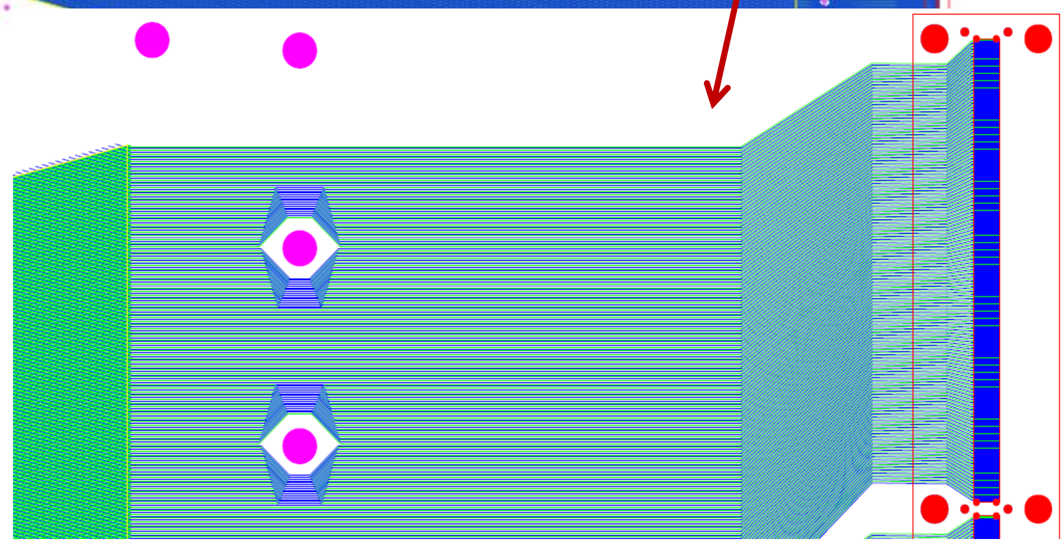
Large GEM R&D: Readout studies for EIC

2D strips in U-V coordinates.

- Angles between U-V strip is 30 deg.
- Expected excellent 2D spatial resolution
- 20 APVs (1280 channels) ⇨ Cost

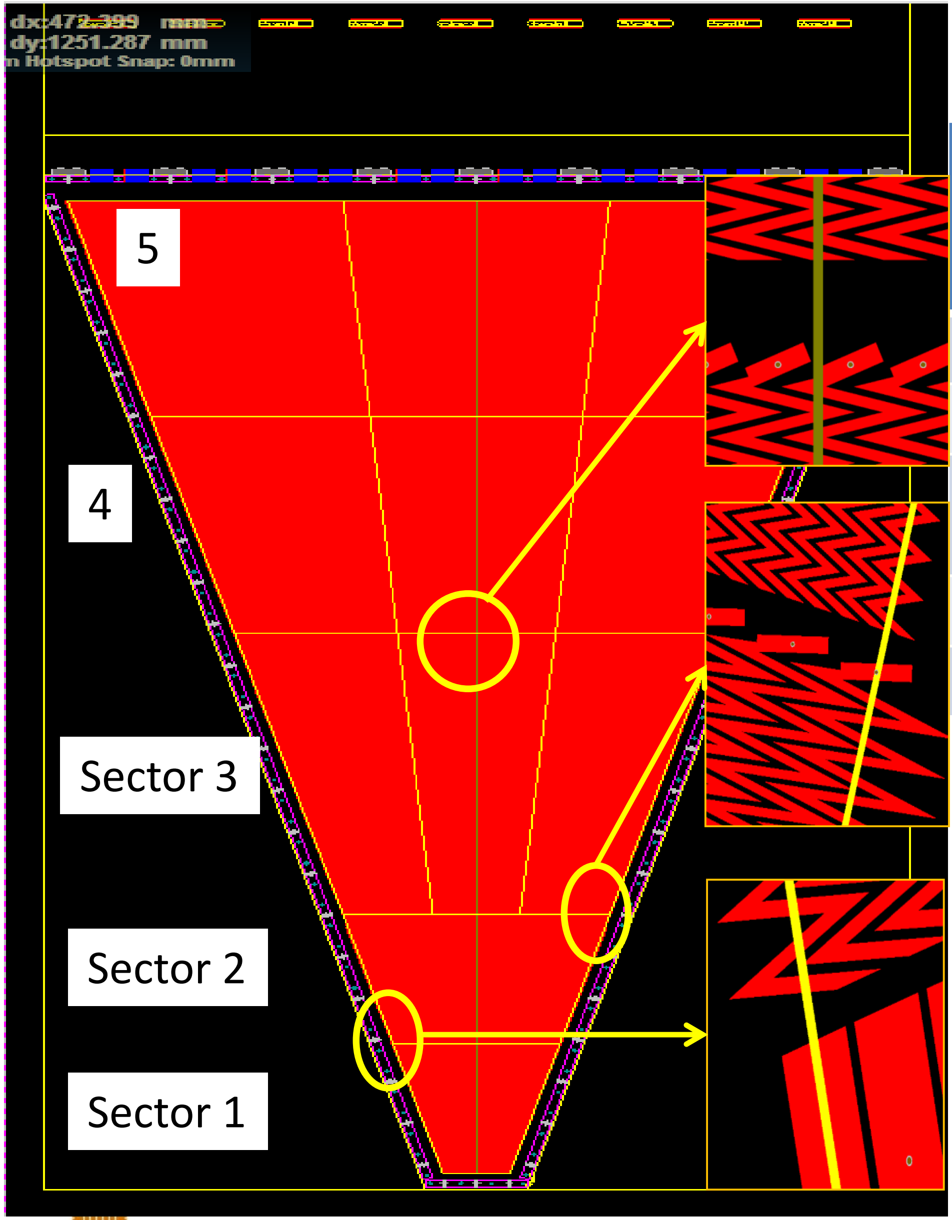






K. Gnanvo from UVa

Large GEM R&D: Readout studies for EIC



Zigzag strips readout

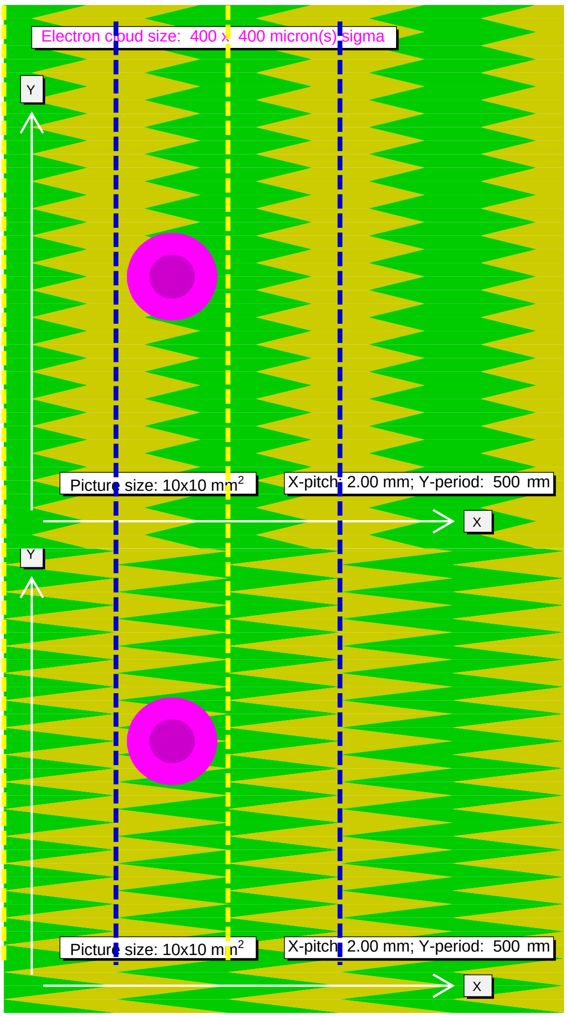
No.	Strip type	No. of strips	Angle pitch (mrad)	Length of sector (cm)
1	Straight	128	4.14	12
2	Zigzag	128	4.14	12
3	Zigzag	384 (=128*3)	1.37	22
4	Zigzag	384	1.37	22
5	zigzag	384	1.37	22

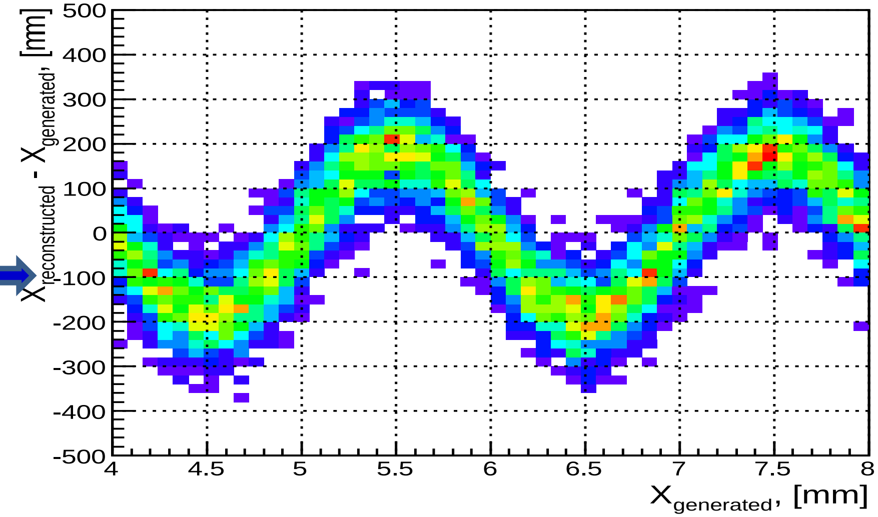
- divide the r/o area into 5 sectors and use straight strip in the innermost sector.
- Total **number of channels is 1152**(=128*9), 9 APVs will be needed to read out the full detector lower electronic cost
- Only 1D position information
- Lower position resolution

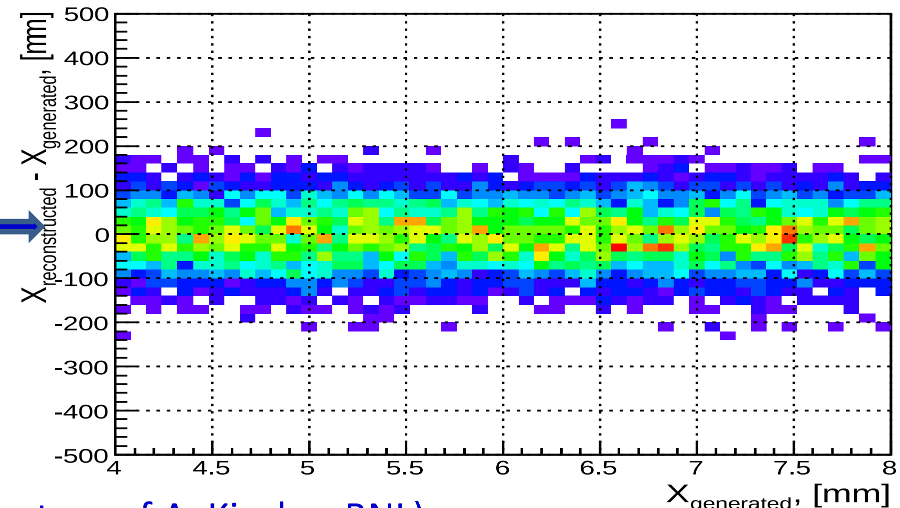
IEEE NSS/MIC 2015, A. Zhang

Large GEM R&D: Readout studies for EIC

-> Type A has been tested in our previous prototype (arXiv:1508.07046), type B will be chosen for the next prototype. The reason is: **<u>type B design gives better charge sharing and shows less non-linear response</u>**.







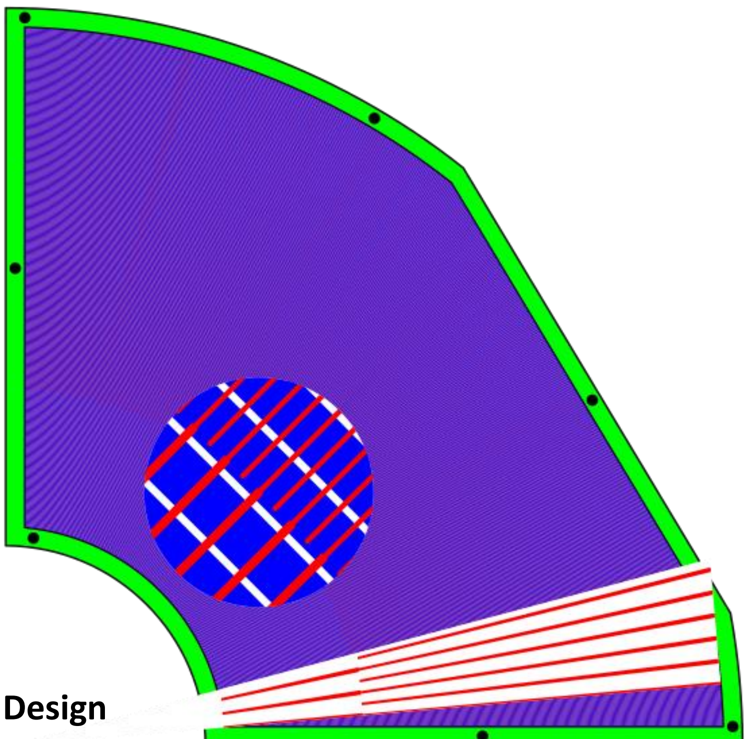
IEEE NSS/MIC 2015, A. Zhang

Simple model simulation results (courtesy of A. Kiselev, BNL)

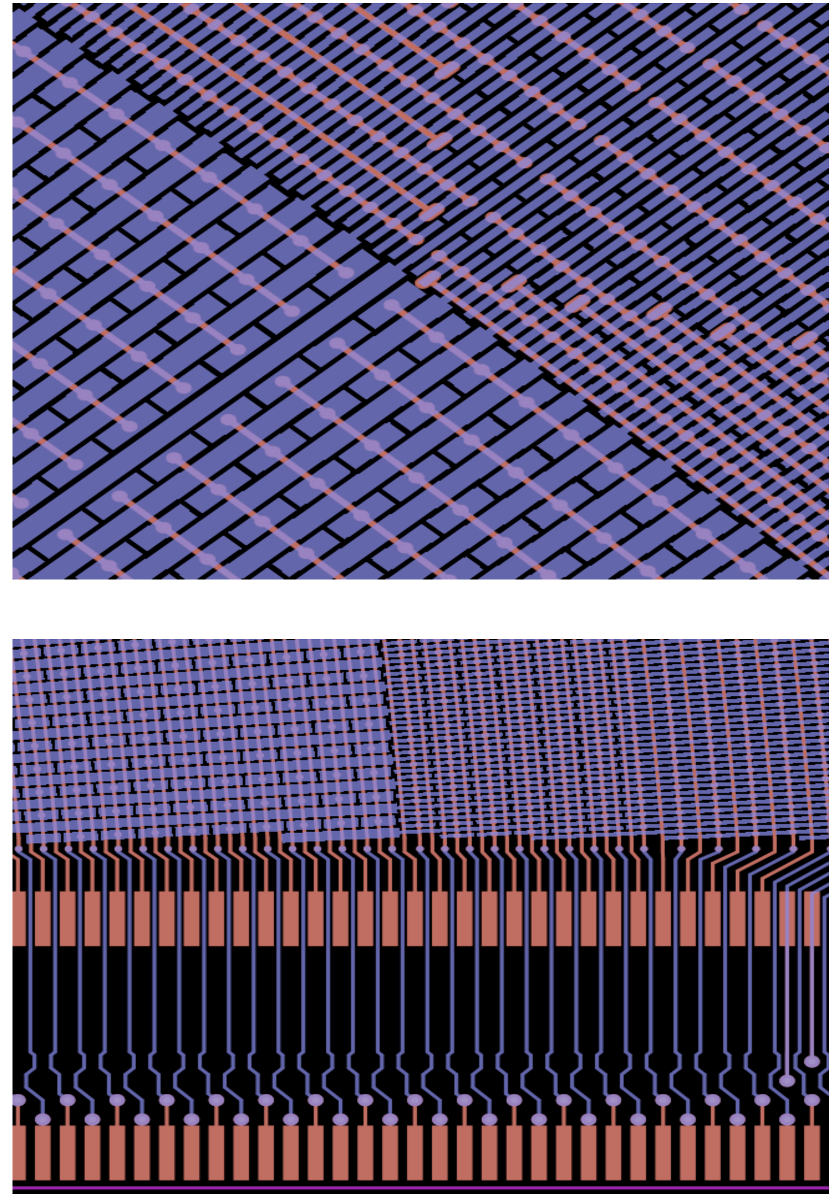
Large GEM R&D: Readout studies for EIC

2D strips in R and ϕ coordinates.

- 2D position information
- Good position resolution



STAR FGT Design
B. Surrow TU

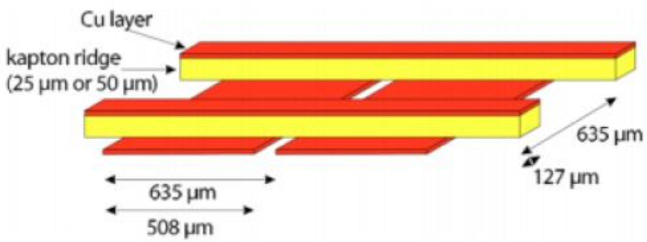


M. Posik from TU

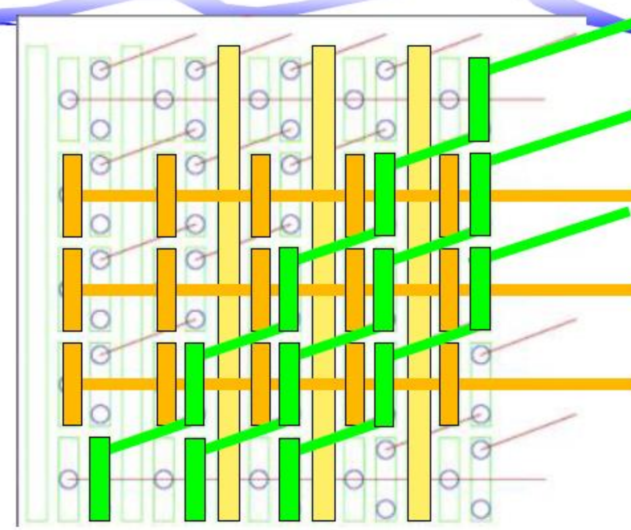
Large GEM R&D: Readout studies for EIC

MT6-2A 3-coordinate readout

D. Majka, Yale U.



Standard Cartesian Readout
- "Compass Style"
- XY Hit Matching by Charge



New 3-coordinate Readout
-Hit matching: GEOMETRY & CHARGE

- **Challenge:**
  Cartesian Readouts can lead to ambiguities in X-Y associations for high multiplicity events.
- **Solution:**
  3 coordinate readout made on double-sided kapton.
- **Goal:**
  Increased tracks per "patch" reduces channel count.

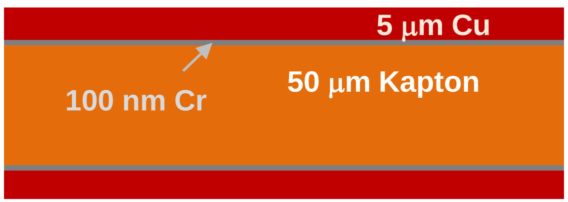
8

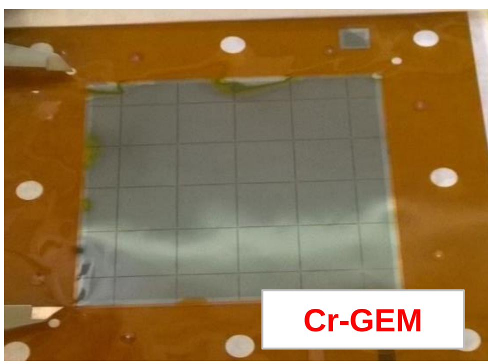
EIC GEM R&D: Low Mass Material R&D

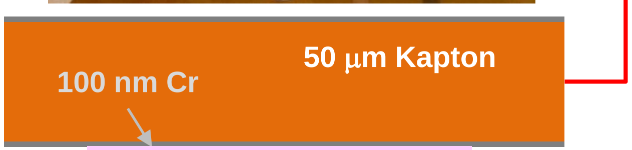
Cr-GEM foil:

- ✓ Copper (Cu) clad raw material comes with 100 nm Chromium (Cr) layer between Cu and Kapton, 5μm Cu layers removed, leave only 100 nm residual Cr layers as electrodes, **Cr-GEM foils provided CERN PCB workshop**
- ✓ Using Cr-GEM foil lead to almost 50% reduction of the material of an SoLID-like light weight **triple-GEM detector**: this is because the material in a lightweight triple-GEM is dominated by the GEM foils & readout board

Standard GEM

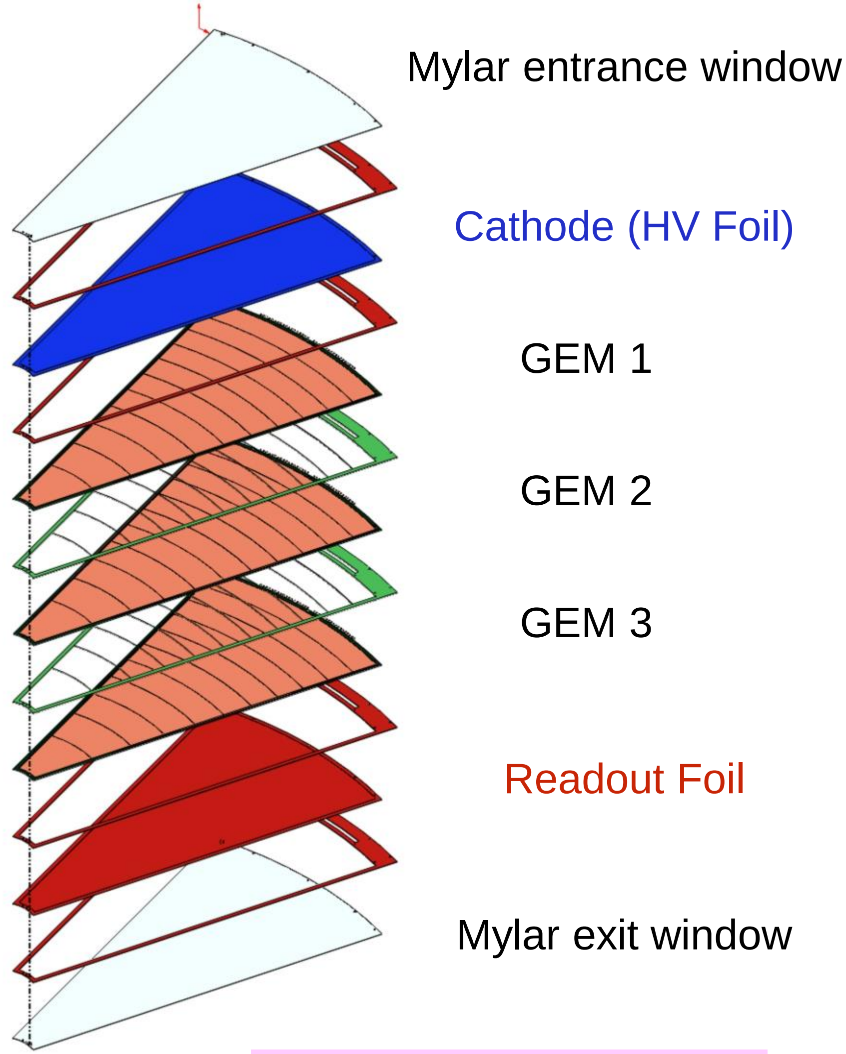






Lower material of GEM foil (UVa)

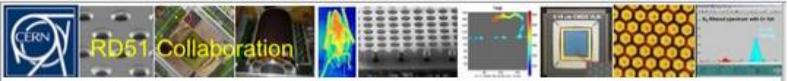
Exploded 3D View



Low material in the assembly design M. Posik (TU)

RD51 Collaboration

RD51 Collaboration



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RD51 Collaboration
Development of Micro-Pattern Gas Detectors Technologies

The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. **The main objective of the R&D programme is to advance technological development and application of Micropattern Gas Detectors.**

The invention of Micro-Pattern Gas Detectors (MPGD), in particular the Gas Electron Multiplier (GEM), the Micro-Mesh Gaseous Structure (Micromegas), and more recently other micro pattern detector schemes, offers the potential to develop new gaseous detectors with unprecedented spatial resolution, high rate capability, large sensitive area, operational stability and radiation hardness. In some applications, requiring very large-area coverage with moderate spatial resolutions, more coarse Macro-patterned detectors, e.g. Thick-GEMs (THGEM) or patterned resistive-plate devices could offer an interesting and economic solution. The design of the new micro-pattern devices appears suitable for industrial production. In addition, the availability of highly integrated amplification and readout electronics allows for the design of gas-detector systems with channel densities comparable to that of modern silicon detectors. Modern wafer post-processing allows for the integration of gas-amplification structures directly on top of a pixelized readout chip. Thanks to these recent developments, particle detection through the *ionization of gas* has large fields of application in future particle, nuclear and astro-particle physics experiments with and without accelerators.

The RD51 collaboration involves ~ 450 authors, 75 Universities and Research Laboratories from 25 countries in Europe, America, Asia and Africa. All partners are already actively pursuing either basic- or application-oriented R&D involving a variety of MPGD concepts. The collaboration established common goals, like experimental and simulation tools, characterization concepts and methods, common infrastructures at test beams and irradiation facilities, and methods and infrastructures for MPGD production.

MicroMegas GEM THGEM MHSP microPIC Ingrid

<u>World-wide coordination of the research in the field to advance technological development of Micropattern Gas Detectors</u>

- <u>Foster collaboration</u> between different R&D groups; optimize communication and sharing of knowledge/experience/results concerning MPGD technology <u>within and beyond the particle physics community</u>
- Investigate <u>world-wide needs</u> of different scientific communities <u>in the MPGD technology</u>
- <u>Optimize R&D financing by creation of common projects</u> (e.g. technology and electronics development) <u>and common infrastructure</u> (e.g. test beam and radiation hardness facilities, detectors and electronics production facilities)
- The RD51 collaboration will <u>steer ongoing R&D activities</u> but <u>will not direct the effort and direction of individual R&D projects</u>
- Applications area will benefit from the technological developments developed by the collaborative effort; however <u>the responsibility for the completion of the application projects lies with the institutes themselves.</u>

RD51 Collaboration Webpage
http://rd51-public.web.cern.ch/RD51-Public

RD51 Conference Contributions, Seminars
http://rd51-public.web.cern.ch/RD51-Public/Documents/ConferenceContributions.html
http://rd51-public.web.cern.ch/RD51-Public/Documents/Seminars.html

RD51 Collaboration: Around the World

The main objective: advance MPGD technological development & associated electronic-readout systems, for applications in basic and applied research”
http://rd51-public.web.cern.ch/rd51-public

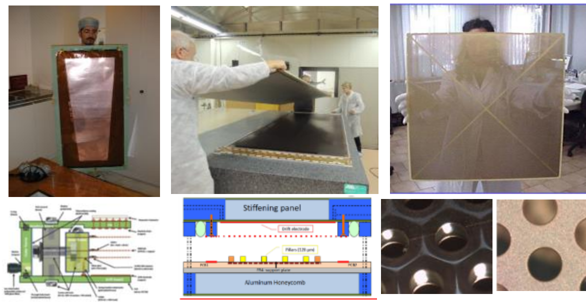
- Large Scale R&D program to advance MPGD Technologies
- Access to the MPGD “know- how”
- Foster Industrial Production

- More than 80 groups
- More than 400 people
- National and International Laboratories
- National Institutes and Universities

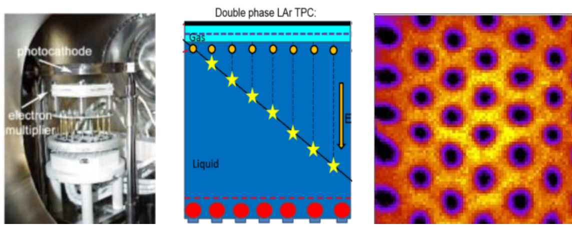
RD51 Collaboration: Working Groups

RD51

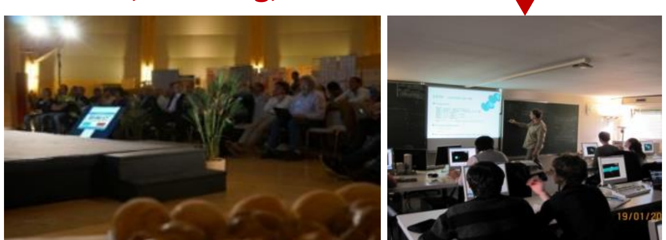
WG1: Technological Aspects and Development of New Detector Structures



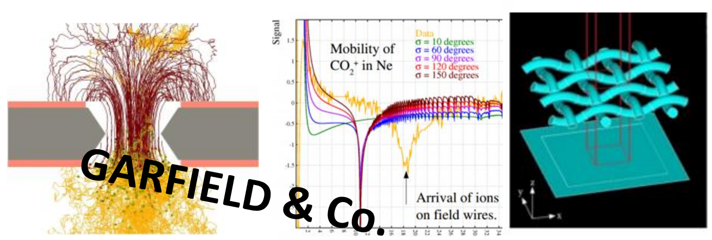
WG2 Common Characterization and Physics Issues



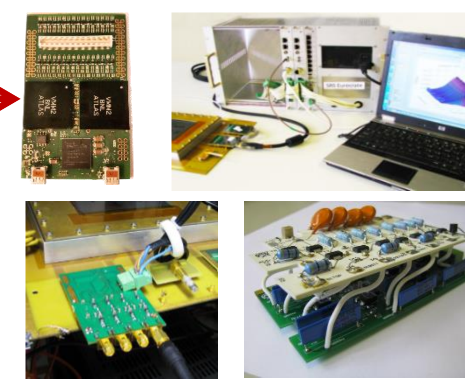
WG3 Academia-Industry Matching Events, Training, Education



WG4: Simulations and Software Tools



WG5: MPGD readout Electronics



WG6: Production, quality control, industrialization

WG7: Common Facilities : Test Beam and Laboratory

RD51 Collaboration: Highlights & Achievements (2008-20015)

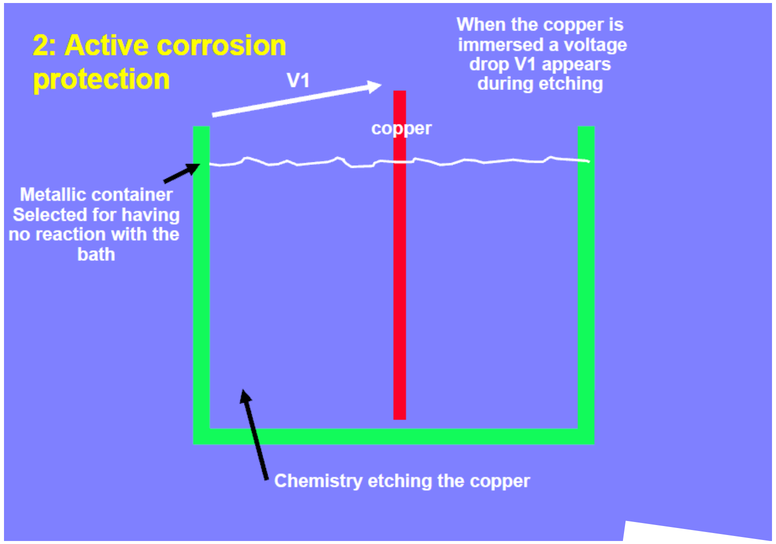
- ✓ Consolidation of the Collaboration and MPGD community integration (>80 Institutes, >400 members);
  - WORLWIDE DISSEMINATION and large support to NEW COMMUNITIES
  - ACADEMIA-INDUSTRY MATCHING EVENTS
  - TRAINING & SCHOOLS
- ✓ Major progress in the MPGD technologies development in particular large area GEM (single mask), MicroMegas (resistive), THGEM; some picked up by experiments (including LHC upgrades);
  - MPGD selected for HEP & NP experiments as a result of these major progresses.
  - PHASE-DRIVEN (R&D or production) SUPPORT
  - NEW REQUIREMENTS (future experiment driven) and NEW AREA of USE
- ✓ Secured future of the MPGD technologies development through the TE MPE workshop upgrade and FP7 AIDA contribution;
  - CERN MICRO PATTERN TECHNOLOGY WORKSHOP scaled up to SQUARE METERS detector size
- ✓ Contacts with industry for large volume production, MPGD industrialization and industrial runs;
  - CONSOLIDATION of the industrial PRODUCTION and manufacturing QUALITY for ALL the main MPGD families.
- ✓ Major improvement of the MPGD simulation software framework for small structures allowing first applications;
  - IMPROVEMENTS on METHODS and TECHNIQUES ; APPLICATION for MPGD optimization
- ✓ Development of common, scalable readout electronics (SRS) (many developers and > 50 user groups); Production (PRISMA company and availability through CERN store); Industrialization (re-design of SRS in ATCA in EISYS);
  - SUPPORT and continuous DEVELOPMENT
  - NEW BASELINE FE ASICS (from experiment development) and STRUCTURES .
  - Development of EASILY accessible MPGD laboratory INSTRUMENTATION.
- ✓ Infrastructure for common RD51 test beam and lab facilities (>20 user groups)
  - Largely ENLARGED infrastructure for the RD51 LAB. REFINEMENT of the TEST BEAM infrastructure.

Summary

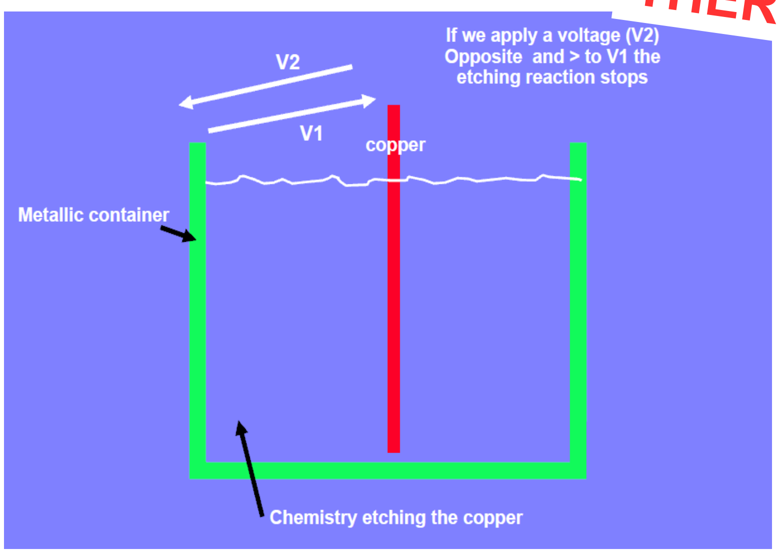
- GEM is a mature technology for future particle physics experiments
- Performances of GEM detectors in term of rate capability, position resolution and low mass material ⇨ Ideal candidate for high precision tracking
- Recent effort in the large area GEM detector technology ⇨ Optimization for Forward Trackers
- Vast ongoing R&D program ongoing in the US for EIC, sPHENIX, SoLID GEM based forward tracking system
- University of Virginia, Florida Tech and Temple University leading US effort in large area GEM technology within the eRD6-eRD3 EIC detector R&D program

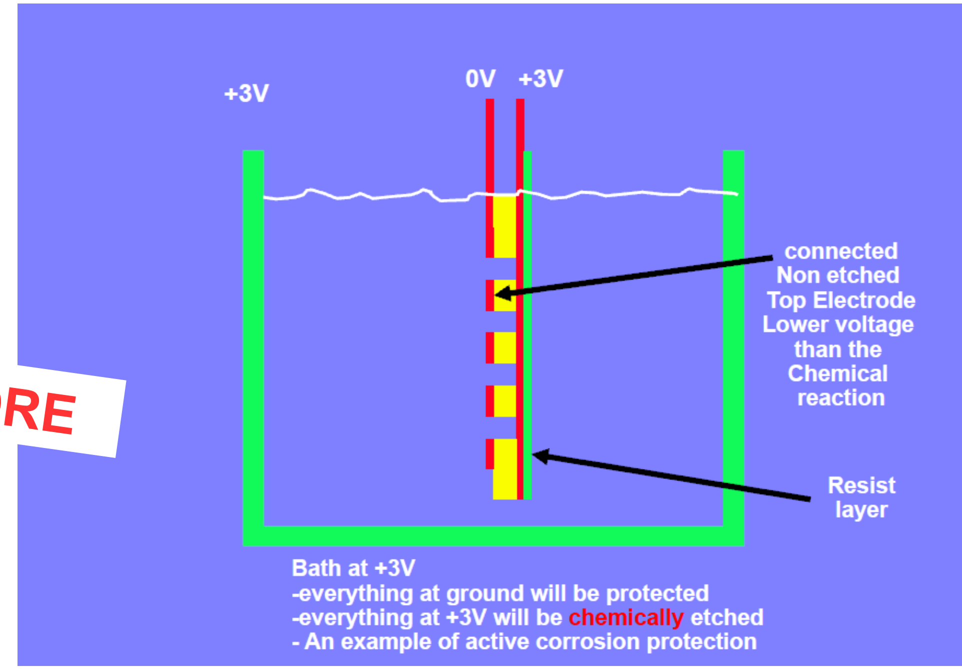
Back Up

Breakthrough With Large GEMs: Single Mask Technique



THEREFORE





Rui De Oliveira, Latest MPGD developments and readout board guidelines, 28 April 2009, RD51 Week

Cylindrical GEM: KLOE-2 Inner tracker @ Frascati, Italy
G. Bencivenni